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GROWTH-PROMOTING VALUE OF THE PROTEINS OF THE PALM KERNEL, AND THE VITAMIN CONTENT OF PALM-KERNEL MEAL[1]

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INTRODUCTION

The oil palm, *Elaeis guineensis*, grows naturally along the West Coast of Africa, but it is also being introduced into other localities. The fruit consists of a kernel or nut inclosed by a hard shell of varying thickness. This hard shell is surrounded by an outer fleshy, oily pericarp from which the commercial palm oil is produced. Palm kernels contain from 45 to 50 per cent of oil, which is removed by expression or by solvent extraction. The resulting oil cake or meal is used as cattle feed. Until comparatively recently, the separation of the oily pericarp from the kernels was made by the natives by means of crude methods, whereby the kernels were subjected to conditions which would tend to denature the proteins, thus rendering them unsuitable for isolation and chemical study.

During the war large quantities of palm kernels were shipped into this country, and it seemed, for a time at least, that they would offer a cheap and nutritious article in such quantity as to become a significant factor in our feedstuff industry. Although there is little or no importation of palm kernels into this country at present, the enormous supply of this source of important feedstuff makes it very desirable to secure as much knowledge as possible regarding its nutritive value.

Palm-kernel meal as a feed for cattle has been given a high rating. Crowther[2] has reported that in digestion experiments with sheep it was found that palm-kernel cake ranks among the most digestible of the stock feeds, and is more valuable than cottonseed meal. Hooper and Nutter,[3] in feeding experiments with milch cows, found that palm-kernel meal could be used with advantage as a supplement to corn for the production of milk.

So far as we are aware, no previous work has been done to ascertain the nutritive value of the proteins of the palm kernel when fed to animals as the sole source of protein in a diet adequate with respect to the other essential dietary factors.

The palm-kernel meal used for the feeding experiments described in this paper was a commercial product which had been prepared by the solvent process. It contained 19.44 per cent of protein ($N \times 6.25$).

[1] Accepted for publication May 2, 1923.

[2] CROWTHER, Charles. PALM KERNEL CAKE. *In* Jour. Bd. Agr. [London], v. 23, p. 734-749. 1916.

[3] HOOPER, J. J., and NUTTER, J. W. FEEDING TRIALS OF VELVET-BEAN FEED, PALM-KERNEL MEAL AND VARIOUS GRAIN MIXTURES, FOR DAIRY COWS. Ky. Agr. Exp. Sta. Circ. 23, p. 31-38, illus. 1918.

The results obtained in these studies show that palm-kernel meal, when fed at a protein intake level of 15.5 per cent of the diet, furnishes protein adequate for the normal growth of albino rats, and that when the meal constitutes as much as 40 per cent of the diet it does not furnish sufficient vitamin A to prevent xerophthalmia, or of vitamin B to provide for normal growth. However, since the meal used for these experiments was a commercial product from which the oil had been removed by the solvent process, and since the history of the kernels prior to the extraction of the oil, involving the treatment they were subjected to in removing the oily pericarp, is unknown, the vitamin deficiencies of the commercial meal used in these experiments may not be characteristic of the fresh, untreated palm kernels.

GROWTH-PROMOTING VALUE OF PALM-KERNEL PROTEINS

Albino rats weighing from 40 to 70 gm. were fed on a diet containing 80 parts of palm-kernel meal, equivalent to 15.5 per cent of protein. The diet was satisfactory with respect to the constituents other than protein. Vitamin B was supplied by a daily allowance of 80 mgm. of a yeast vitamin preparation made according to the method described by Osborne and Wakeman,[4] and 0.3 gm. of cod liver oil furnished vitamin A. In all the experiments the yeast preparation and cod liver oil were given separately from the rest of the diet. The composition of the diet[5] and curves representing the rates of growth are given in chart 1.

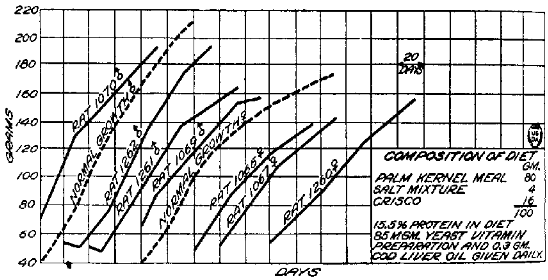

CHART 1.—Curves showing growth-promoting value of palm-kernel proteins.

These curves show that the proteins of the palm kernel are adequate for normal growth when they constitute the sole source of protein at a 15.5 per cent level intake in a diet otherwise nutritionally satisfactory.

EXPERIMENTS SHOWING VITAMIN B DEFICIENCY IN PALM-KERNEL MEAL

Chart 2 shows the results obtained when the rats received no vitamin B other than that which may have been supplied by the palm-kernel meal when this constituted 25 per cent of the diet. In order to insure a sufficient quantity of adequate protein, 15 parts of purified casein[6] were

[4] OSBORNE, Thomas B., and WAKEMAN, Alfred J. EXTRACTION AND CONCENTRATION OF THE WATER-SOLUBLE VITAMINE FROM BREWERS' YEAST. *In* Jour. Biol. Chem., v. 40, p. 383-394, 4 charts. 1919.

[5] For the composition of the salt mixture see: OSBORNE, T. B., and MENDEL, L. B. THE USE OF SOY BEAN AS FOOD. *In* Jour. Biol. Chem., v. 32, p. 374. 1917.

[6] The casein and "crisco" used in the experiments for the study of the vitamin content of the meal had been treated and found to be devoid of both vitamin A and vitamin B. The casein was purified by extraction with 1 per cent acetic acid, followed by several extractions with 50 per cent alcohol, and finally by extraction with ether. The crisco was treated by passing air through it at 100° C. for 6 to 7 hours.

incorporated in the diet. These animals grew at a fair rate during the first 20 or 25 days, then began to decline. At points marked X, the animals were given daily 85 mgm. of yeast vitamin preparation to which

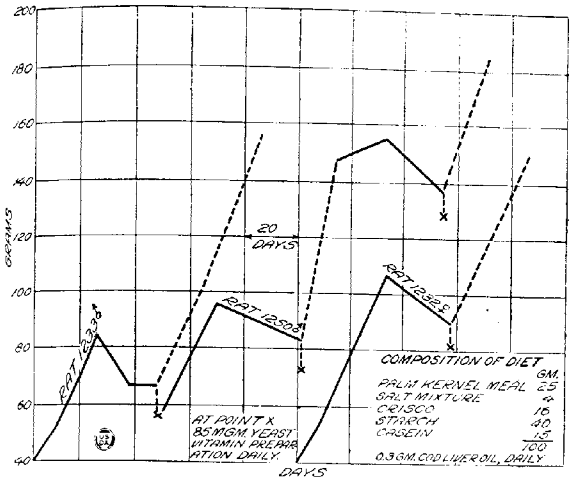

CHART 2.—Curves showing vitamin B deficiency with 25 per cent palm-kernel meal in diet.

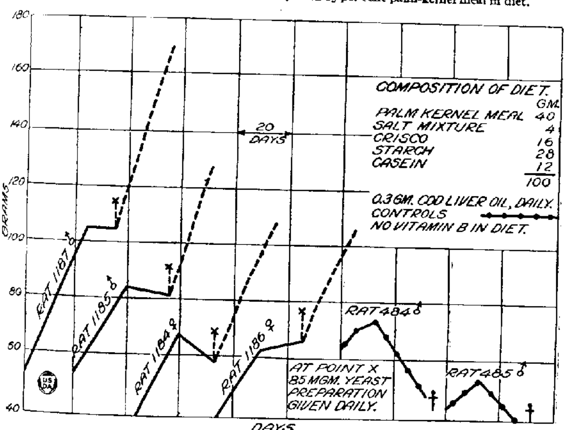

CHART 3.—Curves showing vitamin B deficiency with 40 per cent palm-kernel meal in diet.

they responded promptly, making excellent growths. Rat 1250 ♂ increased in weight from 83 gm. to 148 gm. in 15 days. On being deprived of the vitamin preparation, growth was retarded, and a decline soon

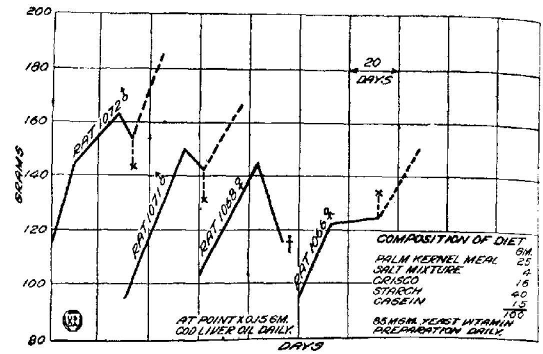

CHART 4.—Curve showing vitamin A deficiency with 25 per cent palm-kernel meal in diet.

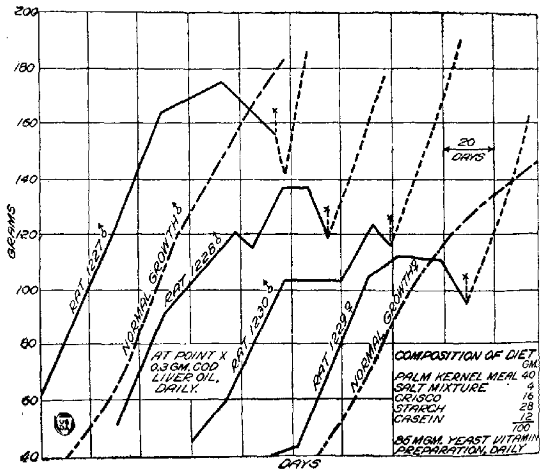

CHART 5.—Curve showing vitamin A deficiency with 40 per cent palm-kernel meal in diet.

followed. Resupplying the animal with the vitamin preparation was again followed by a prompt recurrence of growth.

The curves in chart 3 show that when the quantity of palm-kernel meal was increased to 40 per cent of the diet, there was still a deficiency of vitamin B. That the meal contained some of this vitamin, however, becomes apparent on comparing these curves with those of control rats 484 and 485, which received purified casein as the sole source of protein in their diet. These rats received a diet containing the same percentage of protein as did the others whose growth curves are given in this chart. The control rats made a decidedly slower initial growth and in two weeks began to decline rapidly. It is also to be noted that the animals whose diet contained 40 per cent of the meal did not show decline as soon as those on the 25 per cent meal diet.

EXPERIMENTS SHOWING VITAMIN A DEFICIENCY

The curves in chart 4 show that 25 parts of palm-kernel meal in the diet does not furnish sufficient vitamin A. After an initial growth of 24 to 25 days the rats began to decline and developed xerophthalmia. The addition of 0.3 gm. of cod liver oil promptly cured the eye trouble and enabled the animals to grow at a fair rate. Rat 1068 had declined to such an extent that it failed to respond to cod liver oil.

Where 40 per cent of the meal was used in the diet (chart 5), the decline in growth and onset of xerophthalmia occurred considerably later than in the case of the rats which received the 25 per cent meal ration.

SUMMARY

The proteins of palm-kernel meal were found to be adequate for the normal growth of young rats, when fed in a diet balanced with respect to the other dietary factors. The meal constituted 80 per cent of the diet, which is equivalent to 15.5 per cent of protein.

Forty per cent of palm-kernel meal did not furnish sufficient vitamin A to prevent xerophthalmia, and a like quantity did not provide sufficient vitamin B for normal growth. Since the meal used for these experiments was a commercial product obtained as a residue from the nuts after removal of the oil by the solvent process, the results obtained with reference to vitamin content, however, may not necessarily apply to the fresh, untreated palm-kernel nut.

Inasmuch as it is this treated commercial product which is available for the feeding of live stock, the vitamin values given in this article are of more practical value than would be those found for the fresh kernels.

FFICIENCIES OF PHOSPHATIC FERTILIZERS AS AFFECTED BY LIMING AND BY THE LENGTH OF TIME THE PHOSPHATES REMAINED IN PORTO RICAN SOILS[1]

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INTRODUCTION

Notwithstanding the fact that hundreds of field experiments have been onducted to determine the relative values of the different phosphatic rtilizers, only very few accurate quantitative data on this subject have een obtained. Failure to obtain data has, in most instances, been due o the usual difficulties attending tests of this kind, but in a number of ases it has been due to failure to ascertain whether any of the phosphates ere applied in excess of the crop's requirements. Experiments conucted during the last 15 years with the different phosphates in pot culures have been more fruitful of results in that they have demonstrated uite clearly several general factors influencing the efficiencies of the arious phosphates.

The experiments of Prianischnikov (*21*),[2] Kossowitsch (*13*), Jordan (*9*), hirikov (*2*, *3*), Truog (*31*), Wrangell (*32*), and Bauer (*1*) show that ifferent crops vary greatly in their abilities to utilize the rock phosphates. he last four investigators named suggest that these differences in "feedg power" are correlated with the quantities of lime that are assimilated y the crop, or with the relative quantities of lime and phosphoric acid hat are absorbed.

That the character of the soil affects the efficiences of the phosphates is vident from many field trials and from the work of Kossowitsch (*13*) and edroiz (*4*).

Carbonate of lime markedly decreases the efficiencies of bone meal and ock phosphate, but, according to the results of Kellner and Böttcher *10*, *11*), Söderbaum (*27*, *28*, *29*), Nagaoka (*19*), Prianischnikov *21*, *22*, *23*, *24*), Kossowitsch (*12*), Liechti (*14*), and Mitscherlich (*16*, *17*), does not affect the efficiencies of basic slag, dicalcium phosphate, or the ater-soluble phosphates.

Investigations by Prianischnikov (*21*, *24*), Kossowitsch (*12*), Söderaum (*29*, *30*), and Mitscherlich and Simmermacher (18) show that the soluble phosphates are appreciably more efficient when ammonium ulphate is applied with the phosphate than when sodium nitrate is used s the source of nitrogen.

The effect which carbonate of lime exerts on the efficiencies of the phoshates has become a matter of much practical importance since liming has ecome a general practice. It is especially important to know the effect f applications of lime such as would be required to satisfy the lime equirement of different soils. The work cited above, however, does not

[1] Accepted for publication May 2, 1923.
[2] Reference is made by number (italics) to "Literature cited," p. 193-194.

give much information on this point, since many of the experiments were performed in quartz sand and in other experiments the quantities of lime applied bore no particular relation to the lime requirements of the soils. Also, very little work has been done with a view to ascertaining the rate at which the different phosphates gain or lose in efficiency by remaining in different soils. This is a question of considerable moment in the fertilization of long-time crops, such as fruit trees, sugar cane, and pineapples.

The experiments reported in this paper were conducted to determine the relative efficiencies of acid phosphate, double superphosphate, basic slag, bone meal, and finely ground rock phosphate when used under different conditions in eight types of Porto Rican soils. The results are of general interest, however, in showing quantitatively how the various phosphates are affected by remaining in different soils and by applications of lime which are sufficient to satisfy the "lime requirements" of the soils.

EXPERIMENTAL METHODS

The relative efficiencies of the phosphates were calculated, not from the magnitudes of the increases produced by equal quantities of phosphoric acid, but from the relative quantities of phosphoric acid required to produce the same increase in yield. For example, if 2 gm. of phosphoric acid from floats produced the same increase as 0.5 gm. of phosphoric acid from acid phosphate, the floats phosphoric acid was considered as being 25 per cent as efficient as the acid phosphate phosphoric acid. In order to follow this method of comparison, it was necessary to have in each experiment a series of pots receiving increasing quantities of phosphoric acid from the standard material, acid phosphate. A curve was plotted from the yields of these pots to show the extent to which growth would be increased by any quantity of acid phosphate.[3]

As pointed out in another publication, (*6*) it is believed that this method of comparison is more likely to give accurate results than is the usual method because it is not only not based on any assumption concerning the law of minimum, but it is accurate, irrespective of how growth increases with increasing quantities of the elements in minimum; and it does not necessitate an analysis of the crop.

Basic slag, bone meal, and floats or finely ground rock phosphates, were compared on the basis of their total phosphoric acid content, while acid phosphate and double superphosphate were compared on the basis of their "available" or ammonium-citrate-soluble, phosphoric acid. The efficiencies of the various phosphates are expressed as compared with the efficiency shown by acid phosphate when the latter was applied in the unlimed soil immediately before planting was done.[4]

In the larger experiments the differently treated pots were replicated five times or more. The probable error of the average result for each treatment was therefore fairly low—less in most cases than 4 per cent of the yield. The regularity of the curves showing the increases in growth produced by increasing applications of acid phosphate also confirmed the accuracy of the results.

Millet (*Setaria italica*), which readily responds to phosphoric acid, was used as the test crop. As soon as the seeds had matured and the

[3] A small preliminary test was conducted with each kind of soil to determine approximately the maximum quantity of phosphoric acid to which the crop would respond.

[4] In Experiment VII the yields produced by acid phosphate in the limed soil were taken as the standard for comparison, since in this soil acid phosphate was very ineffective without lime.

heads had turned yellow the plants were cut. This stage of maturity was reached in 36 to 48 days after the plumules had broken the ground, according to the season in which the plants were grown. Both green and oven-dried weights of the heads and stalks from each pot were obtained, but for the sake of conciseness only the oven-dried weights of the combined heads and straw are reported. The ratio of heads to straw appeared to be constant for plants of a given weight in any one experiment, irrespective of the source of phosphoric acid used. Where the larger quantities of available phosphates were used, the growth of the plants was fully equal to that made under good field conditions.

Glazed earthenware pots were used in some of the tests, and tin pots that had been coated with tar paint were used in others. Each container had a capacity of 5 gallons, and both kinds of containers gave equally good results. During the day the pots were kept on trucks in a wire inclosure (5 meshes to the inch) and at night and during heavy rains they were run into a glasshouse. The order of the trucks was shifted daily and the order of the pots on each truck was changed every few days to insure uniform conditions of growth.

As soon as an experiment was started the moisture content of each soil was made up to about 60 per cent of its maximum water-holding capacity, and was kept constant by weighing. When the plants attained considerable size the weights of the pots plus the soil were taken daily, and as the plants became larger, allowance was made for the added weights of the plants. Transpired water was replaced by rainwater containing only 17 parts per million of total solids. The plan of the experiment and the methods of comparison were such, however, that appreciable impurities should not have affected the accuracy of the result (*6*).

The phosphates were thoroughly mixed with the first 4 inches of soil in the pots after the various applications had been made up to the same weight by the addition of silica sand. Whenever the phosphatic fertilizers were added to some of the pots in an experiment, the soil in all the other pots was stirred in a similar manner so that it might be in a uniform mechanical condition in all the pots at the time of planting. The sodium nitrate, ammonium sulphate, and potassium salts were added in solution, half of the total quantity being incorporated with the soil before planting was done, and the remainder when the plants were somewhat less than half-grown. Half the nitrogen was derived from sodium nitrate and half from ammonium sulphate, in order that the efficiencies of the insoluble phosphates might not be appreciably affected by the unassimilated acid and alkaline residues of the nitrogen salts.

In the limed series sufficient lime (air-slaked lime containing some carbonate) was added to each pot to satisfy the lime requirement of the soil as determined by the Veitch method, the lime being thoroughly incorporated with the volume of soil in each pot three or four days before the phosphates were added.

Analyses of the five different phosphates used in the experiments are given in Table I.

TABLE I.—*Analyses of the phosphatic materials which were used in the vegetation tests*

Material.	Total phosphoric acid (P_2O_5).	Water-soluble phosphoric acid.	Citrate-soluble phosphoric acid.
	Per cent.	*Per cent.*	*Per cent.*
Acid phosphate	21.33	14.98	17.27
Rock phosphate	30.63	....	.73
Bone meal	26.03	....	....
Basic slag	17.90	....	[1] 9.57
Double superphosphate	45.70	37.73	44.27

[1] Fourteen per cent available in 2 per cent citric acid.

Soil samples were taken from parts of the field that had not been manured or fertilized for many years, at least. From 5 to 6 tons of each type of soil were used in the experiments. Table II shows the chemical composition of the soils in which the phosphates were tested.

TABLE II.—*Chemical composition of soils in which the phosphates were tested*[a]

Soil constituents.	Soil No. 1524.	Soil No. 1257.	Soil No. 1529.	Soil No. 1578.	Soil No. 1716.	Soil No. 213.	Soil No. 1796.	Soil No. 1810.	Soil No. 1811.
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Silica (SiO_2)	86.17	73.92	97.37	51.32	92.99	53.34	54.41	....	....
Titanium oxid (TiO_2)	.55	.60	.33	1.16	.39	.85	1.13	....	....
Ferric oxid (Fe_2O_3)	2.11	4.48	.62	11.71	1.80	12.45	11.05	....	....
Alumina (Al_2O_3)	5.49	12.36	.78	22.47	2.22	13.03	20.45	....	....
Manganese dioxid (MnO_2)	.056	.35	.018	.37	.174	.16	.06	....	....
Lime (CaO)	.28	.27	.26	.30	.19	2.77	.45	....	....
Magnesia (MgO)	.37	.25	.09	.15	.12	8.27	.62	....	....
Potash (K_2O)	.33	.54	.13	.36	.15	1.54	.54	....	....
Soda (Na_2O)	.06	.07	Trace.	.47	.02	1.44	.29	....	....
Phosphoric acid (P_2O_5)	.02	.09	.01	.43	.03	.15	.06	....	....
Sulphur trioxid (SO_3)	.12	.10	.05	....	.12	.07	.16	....	....
Loss on ignition	5.28	7.53	1.32	12.66	1.88	6.32	12.00	....	....
Total	100.84	100.56	100.98	101.40	100.08	100.39	101.22	....	....
Nitrogen (N)	.15	.14	.06	.26	.05	.03	.21	....	....
Organic matter	3.93	3.80	2.64	3.64	1.75	....	....	....	....
Lime requirement[b]	.103	.108	.056	.176	.006	....	.196	00.272	[illegible]

[a] The samples were analyzed by the Bureau of Soils, U. S. Department of Agriculture, by the method of the Association of Official Agricultural Chemists.
[b] By Veitch method; CaO required expressed as percentage of weight of soil.

All the soils except No. 213 are important agriculturally, and when planted with Citrus or pineapples are heavily fertilized. No. 1524 is a brown, fine sandy loam from Bayamon; No. 1257 is a reddish brown, fine sandy loam from Pueblo Viejo; No. 1529 is a gray sand from Toa Baja; No. 1578 is a clay loam from the Vega Baja-Manati section, and derived from a limestone; No. 1716 is a grayish brown, fine sandy loam from Barceloneta; No. 213 is a medium sand, a riverwash; No. 1796 is red clay from Mayaguez (5); and No. 1810 and 1811 are red and black clay, respectively, from Rio Piedras.

EFFICIENCIES OF THE PHOSPHATES AS AFFECTED BY THE SOIL

Experiments I to VIII, inclusive, were similar in plan, but in each instance a different type of soil was used. The soil in half the series of pots in each experiment received sufficient lime to satisfy its requirement by the Veitch method, and that in the remaining pots was left unlimed. The various phosphates were applied to some of the pots in both the limed and unlimed series six weeks before planting was done, and to the remainder the day before planting. The essential details of each of the eight experiments are given in Table III.

TABLE III.—*Conditions of Experiments I to VIII, inclusive*

Experiment No.	Soil No.	Quantity of moisture-free soil per pot.	Optimum water content of soil.[1]	Sodium nitrate added per pot.	Ammonium sulphate added per pot.	Potassium sulphate added per pot.	Number of plants grown per pot.	Number of days plants grew.
		Pounds.	*Per cent.*	*Gm.*	*Gm.*	*Gm.*		
I	1810	31.2	40.0	5.6	4.0	5.3	15	46
II	1811	37.9	30.0	5.6	4.0	5.3	15	48
III	1716	42.5	12.3	5.6	4.0	5.3	14	40
IV	1529	41.6	13.0	5.6	4.0	5.3	18	43
V	1257	42.6	22.0	6.3	4.5	6.0	15	38
VI	1578	37.8	30.0	5.3	3.8	5.0	18	43
VII	1796	31.1	33.0	5.6	4.0	5.3	14	40
VIII	1524	41.6	29.0	8.4	6.0	8.0	21	36

[1] Expressed in percentage of dry soil.

Table IV shows the relative efficiencies of the various phosphates in both the limed and unlimed soils when the phosphates were applied immediately before and six weeks before planting.

TABLE IV.—*Efficiencies of the five different phosphates in the first eight experiments*

PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING

Experiment I, Soil No. 1524.

Kind of phosphate applied.	Phosphoric acid (P_2O_5) applied per pot.	Soil not limed. Oven-dry yield of individual pots. (Heads, leaves, and stalks.)						Soil not limed. Average oven-dry yield.	Soil not limed. Relative efficiency of the phosphates. (Acid phosphate applied immediately before planting in unlimed soil=100.)	Soil limed. Oven-dry yield of individual pots. (Heads, leaves, and stalks.)						Soil limed. Average oven-dry yield.	Soil limed. Relative efficiency of the phosphates. (Acid phosphate applied immediately before planting in unlimed soil=100.)
	Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
No phosphate	....	4.0	3.8	3.3	3.7	4.6	....	....	....	2.4	2.5	2.0	2.6	2.4	....	....	....
Do	....	3.2	3.7	....	....	....	....	3.8	....	2.3	2.4	....	....	....	....	2.4	....
Acid phosphate	0.30	7.8	8.7	9.9	10.2	9.7	....	9.3	100	9.0	9.2	9.6	9.8	10.9	....	9.7	122
Do	.60	17.9	16.8	25.7	17.1	16.2	....	18.7	100	17.2	15.4	11.8	16.1	16.3	....	15.4	90
Do	1.00	23.0	23.4	25.1	22.2	24.8	....	23.7	100	22.8	22.6	23.1	22.8	23.6	....	23.0	106
Do	1.75	33.4	34.2	30.5	33.1	....	....	32.8	100	31.8	32.2	35.5	32.9	32.3	....	32.9	126
Do	2.75	34.5	37.9	37.1	35.2	36.7	....	36.3	100	37.6	36.4	36.5	41.4	37.4	....	37.9	....
Floats	4.00	12.4	12.7	14.5	11.6	11.8	....	12.6	10	3.3	2.7	3.9	3.6	4.2	....	3.5	2
Bone meal	1.25	28.5	27.4	29.6	23.0	29.2	....	27.5	105	17.7	14.8	17.7	14.0	19.4	....	16.7	46
Basic slag	1.00	27.2	24.1	24.7	26.3	23.2	....	25.1	111	23.7	22.4	21.1	19.4	20.9	....	21.5	93
Double superphosphates	1.00	22.2	18.7	23.3	20.4	24.2	....	21.8	85	20.5	19.1	22.6	19.1	22.2	....	20.7	87

PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING

Acid phosphate	0.60	13.8	11.6	14.0	14.7	11.1	....	13.0	70	9.0	9.0	11.2	12.0	10.1	....	10.3	63
Do	1.75	30.7	28.1	26.9	30.0	31.0	....	29.3	84	25.7	22.5	26.2	29.9	28.3	....	26.5	77
Floats	4.00	14.3	13.2	15.6	15.5	13.4	....	14.4	12	3.3	3.3	4.1	3.4	4.5	....	3.7	2
Bone meal	1.25	24.0	21.2	24.6	27.2	21.6	....	23.9	81	14.1	11.7	13.8	14.3	14.0	....	13.6	39
Basic slag	1.00	17.8	16.8	19.9	19.0	21.4	....	19.0	[illegible]	13.4	15.1	14.7	16.2	15.9	....	15.1	53
Double superphosphates	1.00	[illegible]	[illegible]	[illegible]	17.4	19.0	....	[illegible]	[illegible]	[illegible]	[illegible]	17.1	[illegible]	17.5	....	17.0	[illegible]

	PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING																	
Experiment II. Soil No. 1578.	No phosphate	....	0.2	0.2	0.2	0.1	0.3	....	....	....	0.1	0.2	0.2	0.2	0.2	....	....	....
	Do	....	.2	.2	....	....	....	....	0.2	....	.2	....	....	....	....	....	0.2	....
	Acid phosphate	0.4	6.6	4.6	5.6	5.3	4.9	....	5.4	100	5.5	4.0	2.7	2.2	2.2	....	3.3	60
	Do	.8	12.5	14.0	13.3	10.1	12.0	....	12.4	100	7.9	7.5	9.5	6.9	9.5	....	8.3	70
	Do	1.2	23.1	23.6	22.5	20.4	18.4	....	21.6	100	19.3	20.0	16.2	12.7	12.9	....	16.2	80
	Do	1.8	30.3	28.3	33.3	28.1	30.3	....	30.0	100	19.9	27.9	25.7	27.3	21.1	....	24.4	77
	Do	3.6	38.5	43.5	46.5	41.8	36.2	....	41.3	100	27.5	39.2	31.3	40.2	34.8	....	34.6	71
	Floats	6.0	19.5	21.7	20.8	23.7	21.5	....	21.4	20	1.1	.8	1.2	.8	1.0	....	1.0	1
	Bone meal	1.5	17.0	18.4	21.1	20.5	18.1	....	19.0	72	1.4	5.0	3.5	5.3	....	....	3.8	19
	Basic slag	1.2	20.4	15.3	22.9	19.0	22.6	....	20.0	94	8.6	8.7	11.2	11.0	14.9	....	10.9	60
	Double superphosphate	1.2	25.5	23.6	25.3	20.5	14.4	....	21.9	101	16.1	16.3	11.2	16.9	20.5	....	16.2	80
	PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING																	
	Acid phosphate	0.8	4.4	5.3	4.7	9.1	6.7	....	6.0	54	3.4	3.3	2.8	4.0	6.7	....	4.0	38
	Do	1.8	15.0	18.8	22.5	20.5	19.5	....	19.3	61	11.6	13.7	13.4	14.2	18.4	....	14.3	49
	Floats	6.0	19.4	18.9	18.1	16.1	20.1	....	18.5	18	.8	.5	1.0	1.4	.7	....	.9	1
	Bone meal	1.5	13.2	17.2	16.6	13.8	14.9	....	6.0	60	1.9	2.8	2.5	3.7	2.1	....	2.6	12
	Basic slag	1.2	8.7	10.1	9.6	11.3	11.1	....	10.2	57	5.7	7.1	7.1	6.4	6.4	....	6.5	38
	Double superphosphate	1.2	8.8	10.3	8.7	13.1	9.9	....	10.2	57	9.2	7.5	9.2	9.3	7.5	....	8.5	48
	PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING																	
Experiment III. Soil No. 1257.	No phosphates	....	24.5	23.6	24.4	32.0	13.7	27.7	....	....	25.9	25.3	28.6	24.2	22.9	28.9	....	....
	Do	....	28.6	....	....	....	....	....	24.9	....	29.3	....	....	....	....	....	26.4	....
	Acid phosphate	0.2	29.0	24.0	31.9	28.8	26.0	27.5	27.9	100	....	....	....	....	....	....	....	....
	Do	.4	29.8	26.3	33.8	31.0	32.1	35.7	31.5	100	....	....	....	....	....	....	....	....
	Do	.8	35.0	30.9	33.6	34.6	38.3	35.9	34.7	100	34.5	34.0	30.7	31.4	38.6	38.2	34.6	75
	Do	1.2	37.6	29.5	37.1	38.3	39.8	42.0	37.4	100	....	....	....	....	....	....	....	....
	Do	2.4	48.9	42.2	46.3	48.3	45.6	51.0	47.0	100	....	....	....	....	....	....	....	....
	Floats	4.0	34.6	30.7	34.4	35.1	41.5	34.4	35.1	22	26.4	27.9	31.3	23.8	27.2	31.9	28.1	3
	Bone meal	1.0	32.4	28.2	30.6	33.3	34.3	35.3	32.4	51	29.0	31.5	31.8	29.5	34.8	31.9	31.4	31
	Basic slag	.9	31.9	33.3	33.8	34.2	36.9	30.6	33.5	71	29.7	29.5	30.7	29.9	37.3	36.2	32.2	40
	Double superphosphate	.7	35.3	30.0	34.4	31.4	35.3	32.7	33.2	87	32.3	32.7	32.9	27.9	38.3	29.8	32.3	51

TABLE IV.—*Efficiencies of the five different phosphates in the first eight experiments*—Continued

PHOSPHATES MIXED WITH SOIL 2 WEEKS BEFORE PLANTING

Kind of phosphate applied.	Phosphoric acid (P_2O_5) applied per pot.	Soil not limed.								Soil limed.							
		Oven-dry yield of individual pots. (Heads, leaves, and stalks.)						Average oven-dry yield.	Relative efficiency of the phosphates. (Acid phosphate applied immediately before planting in unlimed soil=100.)	Oven-dry yield of individual pots. (Heads, leaves, and stalks.)						Average oven-dry yield.	Relative efficiency of the phosphates. (Acid phosphate applied immediately before planting in unlimed soil=100.)
Experiment III. Soil No. 1257.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
Acid phosphate	0.4	26.7	22.2	27.6	34.9	32.7	24.4	28.1	52	......	......	......	......	......	......	......	......
Do.	.8	27.2	28.2	29.9	33.5	34.7	30.6	30.7	45	......	......	......	......	......	......	......	......
Floats	4.0	29.7	28.9	38.6	35.6	35.6	32.7	33.5	16	......	......	......	......	......	......	......	......
Bone meal	1.0	27.3	28.6	35.8	35.2	29.7	35.4	32.0	46	......	......	......	......	......	......	......	......
Basic slag	.9	27.8	23.1	34.4	29.1	41.2	30.7	31.1	42	......	......	......	......	......	......	......	......
Double superphosphate	.7	25.5	19.1	34.4	30.6	34.6	32.6	29.5	41	......	......	......	......	......	......	......	......
PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING																	
Acid phosphate	0.4	20.8	24.8	29.8	29.9	33.9	28.2	27.9	50	......	......	......	......	......	......	......	......
Do.	.8	28.1	30.3	29.0	28.4	34.2	35.3	30.9	46	33.1	34.9	33.0	31.9	35.5	32.6	33.5	56
Floats	4.0	30.3	37.5	32.9	38.9	38.2	36.8	35.8	24	24.5	29.0	34.1	28.5	28.1	30.4	29.1	5
Bone meal	1.0	24.0	29.9	29.4	34.4	31.0	37.3	31.0	38	25.4	34.1	33.9	31.1	33.6	31.2	31.6	32
Basic slag	.9	28.0	29.7	32.5	35.5	32.5	34.5	32.1	52	26.1	32.6	39.8	35.4	35.3	34.3	33.9	55
Double superphosphate	.7	28.2	28.6	30.7	31.1	29.5	40.0	31.4	57	29.3	34.9	36.0	32.1	31.8	32.3	32.7	56

Experiment No. IV. Soil No. 1810.																	
PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING																	
No phosphates	...	11.3	8.5	11.6	9.3	11.2	...	...	...	6.4	7.0	8.3	7.6	8.1	...	...	...
Do	...	11.4	12.2	...	...	...	...	10.8	...	7.7	5.7	...	...	...	...	7.3	...
Acid phosphate	0.4	19.4	20.1	14.9	19.1	16.0	...	17.9	100	14.2	13.8	15.1	12.9	15.8	...	14.4	100
Do	.8	21.7	22.3	22.4	24.3	22.9	...	22.7	100	17.0	16.7	21.7	16.7	23.9	...	19.2	100
Do	1.5	27.2	25.8	27.4	25.1	28.5	...	26.8	100	25.4	28.6	27.6	25.0	27.6	...	26.8	157
Do	2.5	30.1	25.9	33.4	36.2	31.2	...	31.4	100	35.4	34.5	39.5	36.5	36.1	...	36.4	...
Do	3.5	35.7	35.3	35.8	29.5	29.4	...	33.1	...	38.6	37.7	39.7	44.1	41.1	...	40.2	...
Floats	4.0	25.6	24.1	25.8	28.1	26.5	...	26.0	34	7.8	8.8	7.6	8.8	7.6	...	8.1	5
Bone meal	1.8	21.8	24.1	22.5	21.5	21.8	...	22.3	43	19.2	16.4	16.0	17.2	16.8	...	17.1	35
Basic slag	1.5	28.3	24.0	27.1	26.8	24.7	...	26.2	92	23.0	24.3	24.3	26.4	24.5	...	24.5	117
Double superphosphate	1.5	25.1	24.7	28.4	23.1	25.8	...	25.4	83	28.1	33.3	26.2	27.7	27.7	...	28.6	...
PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING																	
Acid phosphate	0.8	16.3	20.0	11.3	16.8	19.3	...	16.7	41	14.3	14.5	14.7	13.4	13.9	...	14.2	49
Do	2.5	26.8	26.7	25.4	24.8	30.5	...	26.8	80	26.6	...	28.5	27.9	27.2	...	27.6	98
Floats	4.0	23.4	27.6	27.1	23.4	27.2	...	25.7	32	8.4	8.8	10.8	12.1	12.5	...	10.5	5
Bone meal	1.8	20.3	27.0	22.1	20.7	23.4	...	22.7	44	14.2	15.4	11.8	13.9	12.7	...	13.6	20
Basic slag	1.5	19.2	19.9	20.4	20.7	24.1	...	20.9	37	17.8	16.4	18.1	17.1	14.9	...	16.9	41
Double superphosphate	1.5	21.8	22.3	20.0	20.7	20.8	...	21.1	44	17.6	20.8	16.9	19.3	18.9	...	18.7	51
Experiment No. V. Soil No. 1811.																	
PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING																	
No phosphates	...	6.5	5.1	5.9	5.8	6.0	...	...	...	4.2	5.1	5.4	5.7	5.3	...	...	...
Do	...	5.9	7.1	...	...	...	...	6.0	...	5.4	5.4	...	...	...	...	5.2	...
Acid phosphate	0.4	16.3	16.1	17.6	19.4	19.8	...	17.8	100	17.6	16.3	13.0	18.2	17.2	...	16.5	95
Do	0.8	23.0	24.5	23.5	25.6	22.7	...	23.9	100	24.0	24.9	23.8	23.6	20.9	...	23.4	103
Do	1.5	41.2	35.4	36.7	24.2	36.4	...	36.8	100	41.5	38.5	33.0	31.0	38.0	...	36.4	95
Do	2.5	45.5	49.7	45.7	47.7	46.6	...	47.0	100	39.5	43.5	52.8	42.9	46.8	...	45.1	94
Do	3.5	51.7	56.1	53.5	51.7	56.2	...	53.8	100	49.1	54.1	53.1	53.3	50.5	...	52.0	95
Floats	6.0	26.4	23.9	24.7	23.7	27.7	...	25.3	15	13.8	13.9	16.4	12.4	14.3	...	14.2	5
Bone meal	3.0	20.0	24.5	28.1	36.6	29.4	...	27.7	33	22.5	26.5	24.6	30.9	25.0	...	25.9	32
Basic slag	1.5	30.1	28.8	28.7	28.5	29.6	...	29.1	69	22.2	24.4	27.2	23.3	26.0	...	24.6	59
Double superphosphate	1.5	39.9	39.9	38.1	34.7	36.2	...	37.8	97	29.1	32.1	34.8	29.3	34.7	...	32.0	81
PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING																	
Acid phosphate	0.8	16.8	19.8	19.5	16.9	19.4	...	18.5	55	16.8	17.1	18.5	15.7	13.6	...	16.2	48
Do	2.5	37.1	29.1	47.7	38.8	38.9	...	38.3	59	39.2	39.0	37.5	35.4	35.8	...	37.4	59
Floats	6.0	27.8	20.0	23.9	22.5	24.4	...	23.7	13	12.8	11.3	12.4	10.8	12.2	...	11.9	4
Bone meal	3.0	20.0	31.6	24.7	20.7	33.9	...	26.2	30	20.6	21.8	21.3	17.4	20.6	...	20.3	21
Basic slag	1.5	23.6	24.0	27.5	23.9	23.3	...	24.5	55	20.5	20.2	20.9	21.2	20.5	...	20.7	43
Double superphosphate	1.5	24.0	22.7	29.8	28.7	33.2	...	27.7	66	25.4	26.8	25.1	27.0	29.2	...	26.7	65

TABLE IV.—*Efficiencies of the five different phosphates in the first eight experiments*—Continued

Experiment No. VI. Soil No. 1716.

PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING

Kind of phosphate applied.	Phosphoric acid (P_2O_5) applied per pot.	Soil not limed. Oven-dry yield of individual pots. (Heads, leaves, and stalks.)						Soil not limed. Average oven-dry yield.	Soil not limed. Relative efficiency of the phosphates. (Acid phosphate applied immediately before planting in unlimed soil=100.)	Soil limed. Oven-dry yield of individual pots. (Heads, leaves, and stalks.)						Soil limed. Average oven-dry yield.	Soil limed. Relative efficiency of the phosphates. (Acid phosphate applied immediately before planting in unlimed soil=100.)
	Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
No phosphate	....	20.9	20.3	24.1	19.9	21.7	....	....	....	21.7	20.4	20.7	22.6	21.6	....	....	....
Do	....	24.0	23.7	....	....	....	....	22.1	....	18.0	21.9	....	....	....	....	21.0	....
Acid phosphate	0.15	28.1	29.0	29.1	27.2	31.2	....	28.9	100	28.6	22.9	25.7	28.3	29.7	....	27.0	90
Do	.30	25.5	31.0	31.0	31.1	31.9	....	30.1	100	29.2	28.4	28.8	33.1	31.5	....	30.2	157
Do	.60	32.5	31.3	37.5	34.3	34.2	....	33.9	100	35.2	29.5	38.3	36.0	35.1	....	34.8	138
Do	.90	36.0	32.2	40.3	36.6	37.4	....	36.5	100	37.4	35.6	39.5	34.4	36.5	....	36.7	....
Do	1.50	39.8	35.8	37.6	37.8	35.5	....	37.3	....	38.2	35.7	34.9	36.1	31.8	....	35.3	....
Floats	3.00	25.6	30.7	27.5	29.5	34.9	....	29.6	8	23.4	25.7	29.4	27.2	28.8	....	26.9	4
Bone meal	.90	33.5	34.4	36.3	33.8	33.8	....	34.4	72	31.9	30.6	33.7	33.0	36.2	....	33.1	70
Basic slag	.60	33.3	37.0	31.4	33.8	35.3	....	34.2	105	35.3	30.9	34.5	34.6	34.1	....	33.9	120
Double phosphate	.60	33.1	34.1	33.7	32.9	36.0	....	34.0	100	35.4	31.9	29.0	37.0	37.8	....	34.2	128

PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING

Kind of phosphate applied.	Phosphoric acid (P_2O_5) applied per pot.	Soil not limed. Oven-dry yield of individual pots.						Soil not limed. Average oven-dry yield.	Soil not limed. Relative efficiency.	Soil limed. Oven-dry yield of individual pots.						Soil limed. Average oven-dry yield.	Soil limed. Relative efficiency.
Acid phosphate	0.30	30.1	28.2	28.9	33.4	29.5	....	30.0	96	30.5	26.4	30.4	29.3	30.9	....	29.5	113
Do	.90	35.2	34.5	29.8	32.4	34.7	....	33.3	61	35.8	34.9	32.0	37.8	40.3	....	36.2	....
Floats	3.00	30.8	29.9	29.2	28.3	28.2	....	29.3	7	30.1	30.7	29.8	30.1	29.9	....	30.1	13
Bone meal	.90	32.9	33.3	34.5	32.1	33.2	....	33.2	60	34.3	33.3	34.7	34.1	34.2	....	34.1	83
Basic slag	.60	37.2	30.8	33.5	36.3	36.2	....	34.8	118	35.2	36.1	37.5	35.4	32.2	....	35.2	148
Double superphosphate	.60	[illegible]	35.5	[illegible]	34.3	30.8	....	33.4	95	34.4	35.5	34.1	33.5	34.7	....	34.9	[illegible]

PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING

Experiment No. VII. Soil No. 1529.	No phosphate	....	4.2	3.4	3.7	3.1	5.2	....	....	....	3.2	3.1	3.9	2.0	4.9	....	....	....
	Do	....	4.9	5.7	....	....	....	....	4.3	....	3.6	3.7	....	....	....	....	3.5	....
	Acid phosphate	0.30	18.0	15.5	15.1	11.3	21.1	....	16.2	[1]78	17.6	17.7	18.1	21.4	18.7	....	18.7	[1]100
	Do	.60	19.5	19.1	23.9	23.1	24.8	....	22.1	[1]68	21.5	23.5	29.8	29.8	25.4	....	26.0	[1]100
	Do	1.00	27.4	22.3	27.7	25.3	28.2	....	26.2	[1]58	30.3	32.9	29.7	28.2	32.2	....	30.7	[1]100
	Do	1.75	28.6	23.4	24.5	24.7	28.3	....	25.9	[1]32	35.4	31.0	32.6	33.3	34.3	....	33.3	[1]100
	Do	2.75	31.0	25.1	29.9	23.6	28.3	....	27.6	[1]25	28.3	33.4	33.5	31.5	30.9	....	31.5	....
	Floats	3.50	27.8	28.9	28.3	28.3	29.6	....	28.6	[1]79	4.3	5.6	5.3	7.4	6.1	....	5.7	[1]1
	Bone meal	1.25	32.3	29.5	31.7	30.6	32.5	....	31.3	[1]78	22.6	21.1	28.3	26.3	21.3	....	23.9	[1]34
	Basic slag	1.00	32.4	29.8	34.4	31.6	29.7	....	31.6	[1]100	28.7	31.0	28.1	32.5	32.0	....	30.5	[1]98
	Double superphosphate	1.00	27.2	26.0	24.9	25.9	25.0	....	25.8	[1]56	33.7	30.6	32.3	34.4	29.3	....	32.1	[1]140

PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING

Experiment No. VII. Soil No. 1529.	Acid phosphate	0.60	16.0	17.8	21.0	18.0	16.6	....	17.9	[1]45	15.8	17.0	18.0	19.0	22.3	....	18.4	[1]49
	Do	1.75	28.4	25.1	26.8	26.4	25.1	....	26.4	[1]33	31.6	31.7	29.4	32.4	32.6	....	31.5	[1]69
	Floats	3.50	24.4	22.1	26.5	22.6	31.4	....	25.4	[1]16	3.9	4.7	4.1	7.5	7.4	....	5.5	[1]1
	Bone meal	1.25	29.3	29.7	32.4	28.2	27.4	....	29.4	[1]66	20.3	19.3	19.5	25.5	16.4	....	20.2	[1]29
	Basic slag	1.00	28.5	24.3	31.0	30.9	32.9	....	29.5	[1]83	27.5	26.6	23.6	31.1	22.7	....	26.3	[1]63
	Double superphosphate	1.00	22.3	17.1	22.2	23.4	18.7	....	20.7	[1]35	19.1	23.7	21.1	28.6	29.3	....	24.4	[1]54

PHOSPHATES MIXED WITH SOIL IMMEDIATELY BEFORE PLANTING

Experiment No. VIII. Soil No. 1796.	No phosphate	....	2.2	2.3	3.7	2.8	3.1	....	....	....	2.6	4.4	3.5	3.4	2.9	....	....	....
	Do	....	2.7	2.8	....	....	....	....	2.8	....	2.7	3.4	....	....	....	....	3.3	....
	Acid phosphate	0.2	19.1	20.9	22.1	22.5	24.4	....	21.8	100	11.6	12.7	15.3	17.4	16.8	....	14.8	60
	Do	.4	33.7	35.7	36.9	37.6	39.0	....	36.6	100	24.2	24.0	23.9	29.6	25.9	....	25.5	61
	Do	.8	47.5	48.4	50.7	52.3	46.0	....	49.0	100	32.3	37.3	39.1	34.6	37.3	....	36.1	49
	Do	1.2	51.3	57.0	55.5	59.4	56.6	....	56.0	100	51.8	43.9	53.9	52.3	52.1	....	50.8	73
	Do	2.0	67.7	68.2	59.6	62.7	59.3	....	63.5	100	56.8	52.4	61.1	58.4	57.1	....	57.2	64
	Floats	2.5	51.7	53.6	55.7	60.3	54.6	....	55.2	46	8.1	7.7	12.2	9.4	10.8	....	9.6	3
	Bone meal	1.2	50.3	57.4	61.0	51.6	57.0	....	55.5	98	30.6	18.2	30.5	32.3	29.5	....	28.2	23
	Basic	.8	37.9	43.5	43.2	50.6	45.4	....	44.1	80	37.5	30.1	37.1	34.3	37.9	....	35.4	47
	Double superphosphate	.8	39.8	49.8	47.4	45.1	45.9	....	45.6	86	27.1	33.7	39.1	36.6	38.9	....	35.1	47

PHOSPHATES MIXED WITH SOIL 6 WEEKS BEFORE PLANTING

Experiment No. VIII. Soil No. 1796.	Acid phosphate	0.4	19.9	18.2	19.7	19.9	20.1	....	19.6	45	12.8	16.2	14.8	18.5	12.8	....	15.0	30
	Do	1.2	39.0	41.3	41.5	55.3	42.8	....	44.0	53	31.4	38.2	41.9	36.5	42.4	....	38.1	36
	Floats	2.5	35.7	51.1	39.9	46.8	44.3	....	43.6	25	7.0	12.2	10.4	6.0	7.7	....	8.7	2
	Bone meal	1.2	37.1	45.0	47.4	49.0	45.4	....	44.8	55	20.2	21.8	27.3	19.0	20.2	....	21.7	16
	Basic slag	.8	25.7	32.8	31.4	33.4	36.7	....	32.0	43	25.4	27.4	27.8	29.9	30.1	....	28.1	35
	Double superphosphate	.8	26.5	33.1	35.5	37.5	38.4	....	34.2	46	28.3	25.4	30.0	28.9	28.6	....	28.2	35

[1] In the case of soil No. 1529, the efficiency of the phosphates is compared with that of acid phosphate in the *limed* soil applied immediately before planting taken as 100, since acid phosphate had a low efficiency in this soil without lime.

The plants responded very markedly to phosphoric acid in all the soils, the yields being increased from 2 to 20 times by the largest quantities of acid phosphate applied. In all soils, both limed and unlimed, the larger applications of acid phosphate produced relatively less increments in yield than did the smaller applications, which, of course, is the normal effect of increasing any limiting factor. In the case of soil No. 1810, however, the larger applications of acid phosphate were markedly less efficient in the unlimed soil than they were in the limed soil, although the smaller applications were about equally efficient in both series. In soil No. 1529 all the quantities of acid phosphate applied were less efficient in the unlimed series than in the limed, the differences in efficiencies in the two series being greater with the larger quantities of acid phosphate applied. Obviously, the maximum yields in these two soils were not to be obtained with acid phosphate as a source of phosphoric acid without the use of lime.

Table V summarizes the results obtained in these experiments.

TABLE V.—*Summary of the results obtained in Experiments I to VIII, inclusive, phosphates mixed with limed and unlimed soil*

UNLIMED SOIL

Time of application.	Kind of phosphate applied.[1]	Soil No. 1524.	Soil No. 1578.	Soil No. 1257.	Soil No. 1810.	Soil No. 1811.	Soil No. 1716.	Soil No. 1529.	Soil No. 1796.	Soil No. 213.[2]
Immediately before planting.	Acid phosphate	100	100	100	100	100	100	52	100	[illegible]
Do	Floats	10	20	22	34	15	8	79	46	[illegible]
Do	Bone meal	105	72	51	43	33	72	78	98	[illegible]
Do	Basic slag	111	94	71	92	69	105	110	80	[illegible]
Do	Double superphosphate	85	101	87	83	97	100	56	86	......
6 weeks before planting.	Acid phosphate	77	58	48	61	57	79	39	49	[illegible]
Do	Floats	12	18	24	32	13	7	16	25	[illegible]
Do	Bone meal	81	60	38	44	30	60	66	55	[illegible]
Do	Basic slag	62	57	52	37	55	118	83	43	......
Do	Double superphosphate	72	57	57	44	66	93	35	46	......

LIMED SOIL

Time of application.	Kind of phosphate applied.[1]	Soil No. 1524.	Soil No. 1578.	Soil No. 1257.	Soil No. 1810.	Soil No. 1811.	Soil No. 1716.	Soil No. 1529.	Soil No. 1796.	Soil No. 213.[2]
Immediately before planting.	Acid phosphate	111	72	75	119	96	128	100	61	[illegible]
Do	Floats	2	1	3	2	5	4	1	3	[illegible]
Do	Bone meal	46	19	31	35	32	70	34	23	[illegible]
Do	Basic slag	93	60	40	117	59	120	98	47	[illegible]
Do	Double superphosphate	87	80	51	......	81	128	140	47	......
6 weeks before planting.	Acid phosphate	70	44	56	74	54	113	59	33	......
Do	Floats	2	1	5	5	4	13	1	2	......
Do	Bone meal	39	12	32	20	21	83	29	16	......
Do	Basic slag	53	38	55	41	43	148	63	35	......
Do	Double superphosphate	59	48	56	51	65	123	54	35	......

[1] The values given for acid phosphate are averages of the results yielded by several different quantities of this material.

[2] The results obtained in the river sand, No. 213, are the averages of several experiments described in a previous publication (*7, p. 25-29*).

Floats (finely ground rock phosphate) was a fairly efficient source of phosphoric acid in some of the soils when no lime was used. It was practically without effect, however, when applied to limed soils immediately before planting was done. The uniformity of the very low efficiencies of floats under these conditions, from 0 to 5 in the different soils, is doubtless significant. In quartz sand, floats usually has about

3 per cent of the efficiency of acid phosphate for the gramineae. It is possible that this value represents the relative efficiencies of floats and acid phosphate in soils which do not contain compounds unsaturated with calcium.

Bone meal varied more in efficiency than did any other phosphate according to the character of the soil. In soils No. 1796, 1524, and 1529 it had an efficiency equal to, or greater than, acid phosphate when no lime was applied, while in soils No. 1810, 1811, and 213 it was only about one-third as effective as acid phosphate. In all the limed soils except No. 1716 it was rather an ineffective source of phosphoric acid.

When the results obtained with basic slag are considered, it should be borne in mind that this material was compared with the other phosphates on the basis of its total phosphoric acid content, although it is sold on the basis of its "available" phosphoric acid. In the slag used in the experiments 78 per cent of the total phosphoric acid was soluble in 2 per cent citric acid, that is, "available" by the Wagner method. Considered on the basis of its available phosphoric acid, basic slag was more efficient, on the whole, than was acid phosphate, since in the nine unlimed soils it averaged 87 per cent as efficient as acid phosphate when applied immediately before planting was done. Basic slag was also very effective when it was applied six weeks before planting and when it was used in conjunction with lime.

The efficiency of the phosphoric acid in double superphosphate was practically the same as that in acid phosphate.

It might be expected that the efficiencies of certain phosphates would depend to a considerable extent upon those qualities of the soil which are indicated by the lime requirement. Apparently, however, this is not so. Table VI shows the lime requirements of the soils and the efficiencies of the different phosphates in the soils when applied immediately before planting without the use of lime. The efficiency of each phosphate is expressed relative to 100 for the efficiency of acid phosphate applied under the same conditions, except in the case of soil No. 1529. In the case of this soil the efficiency of each phosphate is expressed relative to 52 for the efficiency of acid phosphate, since acid phosphate was relatively ineffective in this soil without lime. (See Table V.)

Table VI.—*Showing the relation between the lime requirements of the soils and the relative efficiencies of the phosphates*

Soil No.	Lime (CaO) required to neutralize soil.[1]	Efficiency of—			
		Floats.	Bone meal.	Basic slag.	Double superphosphates.
1810	0.272	34	43	92	83
1796	.196	46	98	80	86
1578	.176	20	72	94	101
1257	.108	22	51	71	87
1524	.103	10	105	111	85
1811	.075	15	33	69	97
1529	.056	79	78	100	56
1716	.006	8	72	105	100

[1] Expressed in percentage of soil.

It is apparent from Table VI that none of the phosphates varied in efficiency directly with the lime requirement of the soil. On the whole, floats was far more efficient in soils with high lime requirements than in those with low requirements, but there is no exact correspondence between this measure of the soil's acidity and the efficiency of floats.

Lack of correspondence may be due in part to the fact that the efficiencies of all the phosphates are expressed relative to the efficiency of acid phosphate. The table would in such a case merely show the effect of the lime requirement properties of the soil in altering relative efficiencies. The effect on absolute efficiencies—that is, on the quantity of phosphoric acid required to produce a given increase in crop—can not be judged since the experiments with the various soils were carried on at different times. Moreover, the absolute efficiencies of the phosphates would doubtless depend upon the degree of phosphorus deficiency in the soil as well as upon other factors.

EFFICIENCIES OF THE PHOSPHATES AS AFFECTED BY LIMING

The degree to which liming affected the efficiencies of the different phosphates can best be seen if the data given in Table V are presented in another form. Table VII shows the effect of liming on the efficiencies of phosphates, the efficiency of each phosphate in the unlimed soil being taken as 100 and in the limed soil as relative to 100.

TABLE VII.—*Effect of liming on the efficiency of phosphates* [1]

Soil No.	Phosphates applied immediately before planting.					Phosphates applied 6 weeks before planting.				
	Acid phosphate.	Floats.	Bone meal.	Basic slag.	Double superphosphate.	Acid phosphate.	Floats.	Bone meal.	Basic slag.	Double superphosphate.
1524	111	20	44	84	102	91	17	48	85	[illegible]
1578	72	5	26	64	79	76	6	20	67	[illegible]
1257	75	14	61	56	59	117	21	84	106	[illegible]
1810	119	6	81	127	....	121	16	45	111	[illegible]
1811	96	33	97	86	84	95	31	70	78	[illegible]
1716	128	50	97	114	128	143	186	138	126	[illegible]
1529	192	1	44	98	250	151	6	44	76	[illegible]
1796	61	6	23	59	55	67	8	29	81	[illegible]
213	90	0	15	53	....	....	....	....	....	....
Average [2]	107	17	59	86	108	108	36	60	91	[illegible]

[1] The efficiency of each phosphate in the unlimed soil, applied immediately before, or 6 weeks before planting taken as 100; the efficiency of the phosphates in the limed soil expressed comparatively.
[2] Soil No. 213 not included.

Evidently the effect of lime on the efficiency of the phosphate depends largely upon the character of the soil. In three soils liming had little influence on the efficiency of acid phosphate which was applied immediately before planting was done; in three soils, it depressed the efficiency; and in three soils it increased the efficiency of acid phosphate. The action of lime was equally variable in the different soils in the case of basic slag and double superphosphate. Although the efficiencies of floats and bone meal were depressed by lime in all soils except No. 1716, the extent of the depression varied greatly according to the character of the soil.

The average values [8] given in Table VII indicate the varying degree to which the different phosphates were affected by liming. Acid phosphate, basic slag, and double superphosphate were relatively little affected by liming, while bone meal lost about 40 per cent of its efficiency and floats lost approximately 75 per cent. This is in accord with the results obtained by Prianischinikov (*22*) in sand cultures. While the average values probably indicate the average of the results that might be secured on a large number of different soils, they obviously do not permit of the prediction of the effect of lime on phosphates in any particular soil.

It was desirable to know whether the time elapsing between the application of the lime and the application of the phosphate influenced the degree to which lime depressed the efficiency, and likewise whether the quantity of lime applied had any appreciable influence when sufficient lime was already present to satisfy the lime requirement of the soil. An experiment was therefore conducted to gain such information, a soil in which lime had markedly affected the efficiency of bone meal being used for the purpose.

Experiment IX was conducted in the same manner as those previously described. Each pot contained 20.5 kgm. of soil No. 1524 maintained at a water content of 29 per cent of the dry weight. The basic fertilization consisted of 4.2 gm. of sodium nitrate, 3 gm. of ammonium sulphate, and 4 gm. of potassium sulphate per pot. Twenty plants per pot were grown for a period of 43 days. Two different quantitites of lime were tried. One series of pots received the lime six weeks before either planting was done, or phosphates were applied. Another series received the two quantities of lime the day before the phosphates were applied. Acid phosphate and bone meal were both applied immediately before planting was done. Table VIII gives the results of the experiment.

TABLE VIII.—*Effect of quantity of lime and the time it was applied on the efficiency of bone meal in Experiment IX*

Time lime was applied.	Lime (CaO) applied per pot.	Phosphate applied immediately before planting.	Phosphoric acid per pot.	Oven-dry yield of individual pots.			Average oven-dry yield.	Relative efficiency of bone meal and acid phosphate. (Acid phosphate applied 6 weeks before planting to soil with 21.06 gm. CaO=100.)
	Gm.		*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
Six weeks before planting	21.06	No phosphate	....	2.5	3.4	3.6	3.2	....
Do	21.06	Acid phosphate	.30	11.9	11.4	11.5	11.6	100
Do	21.06	do	.60	22.1	17.7	15.3	18.4	100
Do	21.06	do	1.00	27.7	29.4	27.6	28.2	100
Do	21.06	do	2.00	41.5	40.6	46.8	43.0	100
Do	21.06	Bone meal	1.25	16.3	14.5	13.2	14.7	34
Do	42.12	No phosphate	....	3.0	3.1	3.3	3.1	....
Do	42.12	Bone meal	1.25	5.5	4.1	4.6	4.7	5
Immediately before planting	21.06	No phosphate	....	4.4	4.9	5.5	4.9	....
Do	21.06	Bone meal	1.25	11.3	15.2	14.2	13.6	26
Do	42.12	No phosphate	....	2.8	4.3	3.9	3.7	....
Do	42.12	Bone meal	1.25	4.9	5.8	4.4	5.0	4

[8] The few results secured with soil No. 213 were not considered when the average values were calculated in order that the latter might be comparable for all the phosphates.

Very little difference was observed in the efficiency of bone meal regardless of whether the lime was applied six weeks or one day before the phosphates were used. The quantity of lime applied, however, had a most pronounced effect. The efficiency of bone meal was almost negligible in the presence of a considerable excess of lime, such as was afforded by the 42.12 gm. per pot.

The data given in Table VII show that applications of lime equivalent to the "lime requirement" of the soil may increase, decrease, or be without appreciable effect on, the efficiencies of acid phosphate, basic slag, and double superphosphate, according to the character of the soil. Such quantities of lime may be expected to reduce the efficiencies of floats and bone meal much more generally and to a greater degree.

Table VIII shows that the quantity of lime applied markedly influences the efficiencies of the phosphates. It would therefore be expected that even on soils such as No. 1529 and 1716 where a certain quantity of lime noticeably increased the efficiencies of acid phosphate, basic slag, and double superphosphate, a larger application of lime would have decreased the efficiencies of these materials.

This conclusion is borne out by the results that are being obtained at the Rhode Island Experiment Station (*8*). A certain quantity of lime on the Kingston soil markedly augments the efficiencies of the phosphates for some crops. Liming beyond a certain point has the reverse effect, however. At least, liming beyond a certain point brings about such a condition in the soil that smaller increases are produced by a given quantity of phosphoric acid from some phosphates.

Although pot and field experiments show that liming affects the efficiency of a phosphate in the sense that a given quantity of the phosphate produces a larger or smaller crop increase on limed soil than on unlimed, results obtained with only one or two kinds of phosphates do not necessarily show that liming affects the quantity of phosphoric acid which is in an assimilable condition. It may be that in certain cases liming is without influence on the assimilability of the phosphoric acid applied and merely corrects or exaggerates a soil condition which is so affecting the growth of the plant that it responds less markedly to an increase in the quantity of assimilable phosphoric acid. The depressing effect of lime observed in the experiments reported in this paper, however, are believed to have been due to the effect of the lime on the quantity of phosphoric acid available to the plant; otherwise, it would hardly be understandable why floats should have had such a low and constant efficiency in the limed soils (Table V) and why the efficiencies of some phosphates were depressed less than others.

EFFICIENCIES OF THE PHOSPHATES AS AFFECTED BY REMAINING IN THE SOIL

The extent to which the efficiencies of the various phosphates were affected by remaining six weeks in the unplanted soils is shown in Table IX. In this table the efficiency of each phosphate applied immediately before planting, to either the limed or the unlimed soil, is expressed as 100, and the efficiency of the material applied six weeks before planting is expressed as relative to 100.

TABLE IX.—*Efficiencies of the phosphates as affected by remaining 6 weeks in the soil* [1]

Soil No.—	Unlimed soil.					Unlimed soil.				
	Acid phosphate.	Floats.	Bone meal.	Basic slag.	Double superphosphate.	Acid phosphate.	Floats.	Bone meal.	Basic slag.	Double superphosphate.
1124	77	120	77	56	85	63	100	85	57	68
1578	58	90	83	61	56	61	100	63	63	60
1157	48	109	75	73	66	74	167	103	138	110
1810	61	94	102	40	53	62	250	57	35	....
1811	57	87	91	80	67	56	80	66	73	80
1716	79	88	83	112	93	88	325	119	123	96
1579	75	20	85	83	63	59	100	85	64	39
1796	49	54	56	54	53	54	67	70	74	74
213	54	50	77	....	....	....	....	....	....	....
Average [2]	63	83	82	70	67	65	140	81	78	75

[1] The efficiency of each phosphate, applied immediately before planting to the limed or unlimed soil, is taken as 100; and the efficiency of each phosphate applied 6 weeks before planting, is expressed comparatively.
[2] Soil No. 213 not included.

Incorporation of the phosphates with the soil six weeks before planting diminished the efficiencies of the five phosphates very appreciably in practically all soils whether lime was used or not.[6] The mean values for the different phosphates show that on the whole acid phosphate possibly lost slightly more of its efficiency than did double superphosphate or basic slag in both the unlimed and the limed series. Although bone meal and floats lost still less than did double superphosphates or basic slag, all these materials had a well defined tendency to be less, rather than more, efficient when they were applied six weeks in advance of planting. This is not in accord with the commonly expressed idea that floats and bone meal may be applied before planting is done because their availabilities increase with time.

On the whole, liming did not appreciably affect the losses in efficiency sustained by the various phosphates when the latter were incorporated with the soil. The average results obtained with all the soils indicate that possibly liming diminished the losses of basic slag and double superphosphates very slightly. The differences between the losses in the limed and the unlimed series in the case of these two phosphates, however, are probably no greater than the experimental error.

From these data it would seem that, in judging whether lime should be applied for the sake of its effect on the phosphates, the effect of lime on the immediate efficiency of the phosphate should be considered chiefly.

These results are not in accord with the statement, which has gained authority from constant repetition, that liming tends to maintain the availabilities of phosphatic fertilizers. The results obtained by Wheeler (32) on the after effects of certain phosphates on limed and unlimed soil are to some extent confirmatory of the results reported in this paper. In the field experiments of Wheeler it will be noted that while the total yields of millet and potatoes were far greater on the limed than on the unlimed plots, the increases attributable to the phosphates were much

[6] The results for floats in the limed soils are hardly significant. Liming alone reduced the efficiency of this material to such a low figure that the added effect of remaining in the soil could not be measured with accuracy.

greater in nearly every case on the unlimed plots. The reverse was true, however, in the case of Swedish turnips.

The effect of liming on the loss in efficiency of phosphates evidently varies very considerably according to the character of the soil involved. In some soils, such as that of the Rhode Island Experiment Station, the influence of lime may be so pronounced on certain soil conditions affecting growth of particular crops as to mask entirely the effect of the lime on the efficiencies of the phosphates. This possibly may have been true in the case of soil No. 1529 where the efficiency of acid phosphate was markedly increased by liming.

RATE AT WHICH PHOSPHATES LOSE EFFICIENCY IN THE SOIL

In order to learn whether the losses in efficiency of phosphates remaining six weeks in the soil were about the maximum to be expected, or whether greater losses would have taken place had the phosphates been incorporated with the soil for a period longer than six weeks, supplementary experiments were conducted with four of the soils to secure data on the rate of loss. The experiments were conducted in the same manner as those previously described, except that in some tests 2-gallon glazed pots were used instead of 5-gallon containers. The essential details of the tests are given in Table X.

TABLE X.—*Conditions of Experiments X to XIV, inclusive.*

Experiment No.	Soil No.	Quantity of moisture-free soil per pot.	Optimum water-content of soil.	Sodium nitrate per pot.	Ammonium sulphate per pot.	Potassium sulphate per pot.	Number of plants grown per pot.	Number of days plants grew.
		Kgm	*Per cent.*	*Gm.*	*Gm.*	*Gm.*		
X[1]	213	42.07	18	12.6	9.0	12.0	6	35
XI	1578	17.31	30	3.2	2.3	3.0	20	42
XII	1578	6.21	30	5.6	4.0	5.3	12	33
XIII	1529	19.98	13	4.2	3.0	4.0	16	41
XIV	1524	7.80	25	3.5	2.5	3.3	10	39

[1] In this experiment corn was grown instead of millet.

Table XI gives the results of the experiments.

The results of Experiment X show that, in some soils at least, the loss in efficiency which the phosphates undergo depends to a considerable extent upon the size of the application, the larger application losing much less of its efficiency than the smaller. This was one reason why in the other experiments there were applied quantities near the maximum to which the soil would respond.

As in the previous experiments, the losses in efficiency varied considerably, according to the kind of soil involved. The results on the whole indicated that acid phosphate continued to lose in efficiency the longer it remained in the soil, although the loss was exceedingly small after the first 20 to 30 days. This is illustrated in figure 1, the curve of which is a composite of the curves plotted from the results given in the unlimed series of Table IV, Experiment III, and Table XVI, Experiments X, XI, XII, XIII, and XIV. It does not, therefore, show the rate of loss in any one soil. In this curve the efficiencies of the acid phosphate applied at various lengths of time before planting are plotted relative to 100 for the

efficiency of that which was applied immediately before planting was done.

It should be borne in mind that the losses represented in the curve and in the foregoing tables were in excess of those sustained by acid phosphate applied immediately before planting. Since the plants could not have utilized any appreciable quantities of phosphoric acid during the first 10 to 20 days after they were planted, it is evident that very considerable losses in the efficiencies of the phosphates probably occurred which are not shown in the experimental results. An idea of what these losses were can be obtained by extrapolating the curve beyond its origin to show what the efficiency of acid phosphate would have been had the phosphate been incorporated with the soil the day plants were ready to use it.

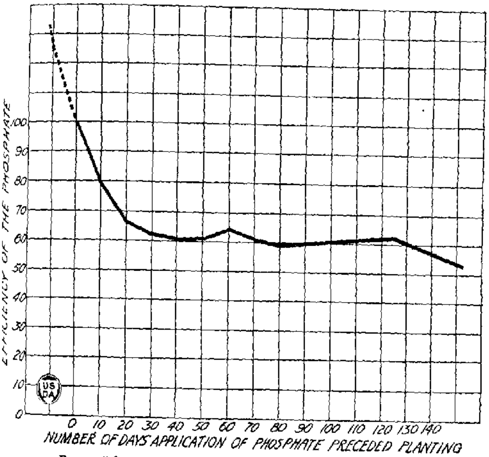

FIG. 1.—Efficiency of acid phosphate as affected by time of application.

These experiments do not show what loss in efficiency might be susined by the phosphates after they had been used on these soils for a ries of years. One is inclined to think that repeated applications of osphates would bring about such conditions in a soil that succeeding plications would sustain smaller losses in efficiency on remaining in the il. The results of long-continued plot experiments, however, do not r the most part support this view, since the later applications of phosatic materials in these experiments do not seem to be relatively more icient than the earlier ones.

The losses in efficiency established in these experiments for phosphates ich remained a short time in unplanted soils are greater than are ually conceived as taking place. In experiments by Schneidewind 5, 26) on a loess soil and a red sandy soil basic slag and acid phosphate parently lost nothing in efficiency by remaining in the soil. There has n very little experimentation along this line, however. Determina-

TABLE XI.—*Results of experiments conducted with four soils to learn the rate at which acid phosphates and basic slag lose their efficiency*

	Time phosphate was mixed with the soil.	Kind of phosphate applied.	Quantity of phosphoric acid (P_2O_5) applied per pot.	Green weight of plants (stalks and leaves) in individual pots.						Average weight per pot.	Relative efficiency of the phosphates. (Acid phosphate applied the day of planting=100.)
			Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	
Experiment X. Soil No. 213	Control	None	0	422	116	128	119	142	....	185	....
	Day planting was done	Acid phosphate	.60	493	270	256	197	256	....	294	100
	Do	do	1.20	502	519	558	296	460	....	467	100
	Do	do	2.10	895	880	850	798	857	....	856	100
	Do	do	3.15	927	1,045	980	1,072	....	....	1,006	....
	18 days before planting	do	.60	225	225	281	255	239	....	245	55
	Do	do	2.10	818	480	797	592	737	....	685	81
	39 days before planting	do	.60	232	282	229	210	232	....	237	48
	Do	do	2.10	719	745	643	634	672	....	683	81
	81 days before planting	do	.60	204	257	222	213	228	....	225	38
	Do	do	2.10	634	763	675	578	584	....	647	77
				Oven-dry yield of plants (heads, leaves, and stalks) in individual pots.						Average oven-dry yield.	
Experiment XI. Soil No. 1578	Control	None	0	0.2	0.2	0.3	0.2	....	....	0.2	....
	Day planting was done	Acid phosphate	.4	5.2	5.8	5.3	6.1	....	....	5.6	100
	Do	do	.8	21.0	11.9	14.8	19.8	....	....	16.9	100
	Do	do	1.2	30.3	21.1	23.2	28.0	....	....	25.7	100
	Do	do	2.0	44.7	37.9	40.9	52.6	....	....	44.0	100
	7 days before planting	do	1.2	21.4	18.3	15.4	17.7	....	....	18.2	72
	14 days before planting	do	1.2	15.9	18.5	18.6	15.5	....	....	17.1	68
	28 days before planting	do	1.2	15.9	17.7	13.6	14.0	....	....	15.3	62
	56 days before planting	do	1.2	13.7	8.8	9.6	8.9	....	....	10.3	48

Experiment XII. Soil No. 1578		None	0	.14	.12	.13	.12	0.20	0.15	.14	....
	Day planting was done	Acid phosphate	.15	4.07	3.71	....	3.39	5.97	3.67	4.16	100
	Do	do	.30	5.69	5.37	5.40	4.69	6.66	5.55	5.56	100
	Do	do	.60	7.43	6.37	8.32	6.76	8.68	6.84	7.40	100
	Do	do	.90	7.86	6.67	7.37	8.67	9.83	8.14	....	....
	Do	do	.90	8.68	....	....	....	....	....	8.17	100
	Do	do	1.80	8.45	9.50	8.55	9.95	9.49	10.61	9.43	100
	20 days before planting	do	.90	6.86	6.67	6.77	7.92	8.20	7.24	7.28	64
	40 days before planting	do	.90	6.51	6.61	6.87	7.41	7.04	7.33	6.96	59
	83 days before planting	do	.90	6.44	7.08	6.40	7.18	7.57	7.78	7.08	61
	125 days before planting	do	.90	8.49	6.07	6.94	7.58	6.09	7.73	7.15	62
	167 days before planting	do	.90	6.69	4.23	7.37	5.96	7.14	7.50	6.48	50
Experiment XIII. Soil No. 1529	Day planting was done	None	0	3.9	2.6	3.0	2.2	....	....	2.9	....
	Do	Acid phosphate	.2	11.9	11.0	10.2	9.6	....	....	10.7	100
	Do	do	.4	20.5	18.8	17.1	12.2	18.4	....	17.4	100
	Do	do	.8	25.2	32.6	25.2	28.8	....	....	28.0	100
	Do	Basic slag	.4	28.7	21.2	26.5	21.5	....	....	24.5	168
	14 days before planting	Acid phosphate	.4	16.6	19.7	16.4	15.3	....	....	17.0	96
	Do	Basic slag	.4	22.7	26.6	20.1	20.7	....	....	22.5	149
	28 days before planting	Acid phosphate	.4	13.6	10.2	18.8	10.9	....	....	13.4	70
	Do	Basic slag	.4	16.6	15.5	19.2	17.9	....	....	17.3	99
	56 days before planting	Acid phosphate	.4	14.6	13.6	14.7	13.9	....	....	14.2	76
	Do	Basic slag	.4	21.0	17.3	15.2	15.3	....	....	17.2	99
	88 days before planting	Acid phosphate	.4	9.1	15.6	11.6	10.5	10.8	....	11.5	55
	Do	do	1.2	29.8	28.0	27.5	29.6	26.7	....	28.3	68
Expr. XIV. Soil No. 1524	Control	None	0	.6	.7	.8	.9	....	....	.8	....
	Day planting was done	Acid phosphate	.2	5.5	5.1	4.9	4.1	....	....	4.9	100
	Do	do	.4	9.6	8.5	9.0	8.8	....	....	9.0	100
	Do	do	.6	12.8	10.0	14.1	12.5	....	....	12.4	100
	14 days before planting	do	.4	6.6	6.4	6.9	5.6	....	....	6.4	69
	28 days before planting	do	.4	6.0	5.7	6.0	4.9	....	....	5.7	60
	56 days before planting	do	.4	4.7	4.8	5.6	6.3	....	....	5.4	55

tions that have been made of the "residual" or "after-effects" of phosphatic applications have not been so conducted as to throw much light on this subject.[7]

That such losses in efficiency or in "availability" may be very considerable and very general seems to be indicated by the fact that as a rule only a small portion of the phosphoric acid applied to the soil is recovered in the crop. While recoveries in the crop of 60 to 90 per cent of the nitrogen or potash applied are common, recoveries of phosphoric acid usually range much lower—from 10 to 20 per cent (*15*), or sometimes even 2 per cent. That this low recovery of phosphoric acid is due to interaction between phosphates and certain soil constituents is indicated by the experiments of Pfeiffer and Simmermacher (*20*) in quartz sand.

SUMMARY

(1) The relative efficiencies of acid phosphate, rock phosphate, bone meal, basic slag, and double superphosphate were tested in nine different soils in which millet was grown as the crop. The effect of the length of time the phosphates remained in the soil and the influence of liming on the relative efficiencies of the phosphates were also determined.

(2) The relative efficiencies of all the phosphates varied widely in the different soils. Bone meal and rock phosphate were particularly affected by the character of the soil. In one soil the efficiency of rock phosphate was about the same as that of acid phosphate, while in another soil it was only 4 per cent that of acid phosphate.

(3) None of the phosphates varied in efficiency directly with the lime requirement of the soil, although rock phosphate and bone meal were generally most effective in the soils with high lime requirements.

(4) Applications of lime equivalent to the lime requirement of the soil (determined by the Veitch method) decreased the efficiencies of acid phosphates, basic slag, and double superphosphate in some soils and increased them slightly in others. In two soils liming had little influence on bone meal, but in the seven other soils it markedly decreased the efficiency of the bone meal. The efficiency of rock phosphate was decreased by liming to an approximately constant value in all soils—about 3 per cent that of acid phosphate.

(5) Practically no difference in efficiency was observed regardless of whether the lime was applied to the soil six weeks before or immediately before the phosphate was applied.

(6) A considerable further decrease in the efficiency of bone meal occurred when the quantity of lime applied was increased beyond the amount indicated by the lime requirement of the soil.

(7) It is probable that even in those soils where the efficiencies of acid phosphate, basic slag, and double superphosphate were increased by the quantity of lime applied a larger application of lime would have decreased the efficiencies of these materials.

(8) A comparison was made of the efficiencies of the phosphates applied six weeks before planting with the efficiencies of the materials applied immediately before planting. When the phosphates remained six weeks in the soil the efficiencies of the five phosphates diminished very appreciably in all soils whether limed or not. The losses in efficiency attributable to the phosphates remaining in the soil were greater

[7] This is chiefly due to the fact that the crop residues have not been removed before the second crop was planted, and it is therefore impossible to ascertain how much of the phosphoric acid assimilated by the second crop was secured from the decomposition of the organic residues of the first crop and how much from the unassimilated phosphoric acid left in the soil

in the cases of acid phosphate, basic slag, and double superphosphate than in the case of bone meal or rock phosphate.

(9) Acid phosphate continued to lose in efficiency the longer it remained in the soil, although after the first 20 to 30 days the loss was exceedingly small. That such losses in efficiency are of general occurrence and that they are due to the action of soil constituents rendering the phosphoric acid unavailable to the plant is indicated by the fact that, as a rule, only 10 to 20 per cent of the phosphoric acid applied is recovered in the crop, whereas 60 to 90 per cent of the nitrogen or potash applied is commonly recovered.

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GROWTH OF FRUITING PARTS IN COTTON PLANTS[1]

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INTRODUCTION

The rate of development of the cotton plant and especially of the fruiting branches, deserves more consideration in connection with studies of cultural methods and weevil-control problems.

During the past three years data have been recorded on the order and rate of appearance and growth of floral buds, the sequence of flowers, and the growth of bolls. These studies have been carried on under different conditions and upon different types of cotton, as indicated in the following outline:

1. Grown under the dry atmospheric conditions of the irrigated valleys of Arizona: Pima variety of the Egyptian type, Upland varieties of Lone Star, Acala, and Durango.
2. Grown under drought conditions on the "Black Land" belt near Greenville, Tex.: Lone Star.
3. Grown under conditions of high humidity at James Island near Charleston, S. C.: Sea Island and Meade.

Thus it is possible to make comparisons of corresponding phases of plant growth and development with different types of cotton under a wide range of environmental conditions.

The records summarized in the following tables show a very close agreement in the rate of appearance of floral buds and blooms between distinct species and types of cotton grown under different conditions. Considerable variation was observed between varieties in the period of development of the floral bud and in the interval from date of flowering to boll maturation. This indicates the importance of considering the relation of varietal and environmental factors to the growth rate.

PRODUCTION OF THE FRUITING BRANCHES

The main stalk of the cotton plant is formed by the development of successive internodes. At each node two buds are normally developed, an axillary bud which produces the vegetative branch and an extra-axillary bud which produces the fruiting branch. The axillary bud stands just above the middle of the base of the subtending leaf and usually remains dormant except on the first few nodes at the base of the stalk. The extra-axillary bud is developed to the right or left of the axillary bud. The specialized nature of the axillary and extra-axillary buds and the tendency for each to develop on definite groups of nodes

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on the main stalk has been recognized and described in several publications.[2]

The rate at which fruiting branches are formed on the main stalk is an important factor in the production of fruit. Data on formation of branches have been obtained in the United States from several varieties of cotton, at Sacaton, Ariz., Greenville, Tex., and Charleston, S. C. The data from Sacaton and Charleston show the intervals between the first appearance of floral buds on successive branches, while those from Greenville show the intervals between the flowers. Harland[3] working with Sea Island cotton in the West Indies determined the rate of appearance of fruiting branches by using the interval between flowers on the first nodes of successive branches.

The first indication of a new fruiting branch is the appearance of a minute triangular bud, commonly called a "square," deeply inclosed between the stipules of the primary leaf. The appearance of the square always precedes the development of the internode on which it is borne, and may therefore be considered as a definite indication of the formation of a fruiting branch. Table I gives the mean interval between the appearance of successive fruiting branches for each variety. It is evident that there is a close agreement of varieties in the rate of production of fruiting branches.

TABLE I.—*The rate of formation of fruiting branches of different types of cotton*

Variety.	Locality.	Year.	Average number of days between the appearance of successive fruiting branches.
Lone Star	Sacaton, Ariz.	1921	3.30±0.088
Acala	....do.	1921	2.80± .067
Durango	....do.	1921	2.87± .097
Pima Egyptian	....do.	1921	2.81± .043
Lone Star [1]	Greenville, Tex.	1922	2.36± .038
Meade	Charleston, S. C.	1922	3.03± .136
Sea Island	....do.	1922	2.86± .081

[1] Figured from number of days between flowering dates.

It should be stated that these data represent the mean number of days between the appearance of successive fruiting branches for the entire period of observation. A comparatively wide range in the interval between the appearance of branches was found, but no significant difference could be traced for different periods of growth or groups of nodes. Individual records of the number of days between the appearance of branches ranged from one to six days, but these differences occurred at no definite period.

[2] COOK, O. F. DIMORPHIC BRANCHES IN TROPICAL CROP PLANTS. U. S. Dept. Agr. Bur. Plant Indus. Bul. 198, 64 p., 9 fig., 7 pl. 1911.
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McLACHLAN, Argyle. THE BRANCHING HABITS OF EGYPTIAN COTTON. U. S. Dept. Agr. Bur. Plant Indus. Bul. 249, 28 p., 3 pl. 1912.

[3] HARLAND, S. C. MANURIAL EXPERIMENTS WITH SEA ISLAND COTTON IN ST. VINCENT, WITH SOME NOTES ON FACTORS AFFECTING THE YIELD. *In* West Indian Bul., v. 16, p. 183. 1917.

The data from Sacaton and Charleston were obtained under conditions of unchecked growth, and no seasonal variation in the rate of branch formation was shown in the records. At Greenville, however, the development of the plants was stopped by a drought in July and August. The checking effect of this drought was apparent late in July, and all squares produced after that period were shed before the flowering stage was reached. Yet the interval between first blooms of successive branches at the end of the flowering period was not consistently longer than the interval between blooms early in the season. This indicates that a reduced rate of growth of the plants did not materially influence the rate of appearance of fruiting branches during the flowering period. It is possible, however, that if the subsequent squares had reached the flowering stage, a definite increase in the interval between blooms might have been found.

The data on Lone Star grown at Sacaton, Ariz., and Greenville, Tex., show the widest difference in the mean interval between the appearance of fruiting branches. The data on the other varieties show a close agreement in the rate of production of fruiting branches. That such uniformity in rate of production could be obtained under widely different conditions of soil, climate, and moisture seems remarkable.

GROWTH OF FRUITING BRANCHES

The fruiting branch is formed by the development of a series of joints, or internodes, each bearing a floral bud, or "square." As described previously in this paper, the first indication of the fruiting branch is the appearance of a minute square and its subtending leaf, inclosed between the stipules of the leaf on the axis. Following the appearance of the square, the first internode of the fruiting branch begins to lengthen, carrying the square and its leaf away from the main stalk. As growth proceeds in the first internode of the fruiting branch, the bud which will form the second node slowly develops until the second square and subtending leaf may be seen. This procedure is followed throughout the growth of the fruiting branch, the preceding node growing for a certain interval before the next square appears.

Different types and varieties of cotton differ in the length and the number of internodes of the fruiting branch. The rate of production of squares, however, is the factor of greatest importance to be considered, particularly under boll-weevil conditions.

In the season of 1921 at Sacaton, Ariz., the date of appearance of each square on each branch was recorded on 10 plants each of the following varieties: Lone Star, Durango, Acala, and Pima Egyptian. From these records it is possible to find the average number of days between the appearance of successive squares on any branch or at any group of internodes.

A similar series of records was obtained in 1922 on the Sea Island and Meade varieties of cotton grown at Charleston, S. C. Data were obtained on the Lone Star variety at Greenville, Tex., the interval in this case being determined by the number of days between blooms on successive internodes.

These data, presented first in Table II, show an average of about six days between the appearance of successive squares for all the fruiting branch internodes of the plant. It will be noted that the production of new squares on the fruiting branches proceeds at Sacaton at the same

rate, regardless of the variety, although they represent widely different types.

While the Meade and Sea Island are distinctly different types of cotton and were grown under conditions where rainfall is frequent and a relatively high percentage of humidity obtains, the interval between the appearance of the square remains the same as with other varieties grown under irrigation in the Southwest.

It will be noted that the mean number of days between the appearance of squares on fruiting branches of Lone Star grown at Sacaton, Ariz., is about one day more than for the same variety grown in Texas. The fact that appearance of squares was used at one place while date of flowering was used at the other could hardly explain this difference. It is possible that the short flowering period at Greenville, caused by drought, may have resulted in a lower mean interval than would have resulted from data obtained over a longer period.

The records obtained at Greenville represent data from flowers on fruiting branches developing from the seventh to the thirteenth node of the main stalk. At Sacaton, however, the data on appearance of squares were obtained from branches developing from the twelfth to the twenty-first node. The difference in the interval between squares or blooms at the two places, if significant, should probably be attributed to the fact that data were obtained at different stages of plant development.

RATE OF APPEARANCE OF SQUARES IN RELATION TO CLOSE SPACING OF PLANTS

The fact that first squares on successive fruiting branches are produced more rapidly than successive squares on the fruiting branches is of practical significance in connection with the cultural advantages that have been obtained by the use of closer spacing of plants in the row. As the first squares on successive fruiting branches appear at about three-day intervals, while successive squares on the fruiting branches appear at about six-day intervals, a more rapid setting of fruit would be expected if the number of plants was increased. With a larger number of branches, resulting from more plants to the acre, better advantage is taken of the more rapid production of squares on the first node of successive fruiting branches.

TABLE II.—*The rate of appearance of successive squares on fruiting branches*

Variety.	Locality.	Year.	Mean number of days between the appearance of successive squares on the fruiting branches.
Lone Star	Sacaton, Ariz	1921	6.60±0.[illegible]
Acala	.....do	1921	6.10± .[illegible]
Durango	.....do	1921	6.30± .[illegible]
Pima-Egyptian	.....do	1921	6.36± .[illegible]
Lone Star [1]	Greenville, Tex	1922	5.65± .[illegible]
Meade	Charleston, S. C	1922	6.0 ± .[illegible]
Sea Island	.....do	1922	6.1 ± .[illegible]

[1] Figured from number of days between flowering dates.

LATE SEASON INCREASE IN INTERVAL BETWEEN SQUARES

There is a tendency for the interval between the appearance of squares) lengthen as the season advances. This is shown in Table III which ives the number of days between the appearance of successive squares n 10 Pima Egyptian plants for three 3-week intervals. In 1921 the mean eriod for the squares produced from June 15 to July 5 was 5.36 days, om July 6 to July 26 it was 6.45 days, and from July 27 to August 15 was 7.53 days. It can be seen that the mean period for each successive ree weeks was longer. These data are substantiated by figures on ima at Sacaton in 1920, which showed that the period between the pening dates of flowers on successive internodes was gradually increasing. his also is shown in Table III. It will be noted that the increase is reater in the 1920 data, but this may be ascribed to the fact that the eriod from the appearance of a square until it flowers is slightly increased s the season advances, thus tending to make the interval between ccessive flowering dates slightly greater than the interval between the ppearance of successive squares.

ABLE III.—*Mean interval between the appearance of successive squares or flowers on fruiting branches for three consecutive 3-week periods, at Sacaton, Ariz.*

	Period I, June 15 to July 5.	Period II, July 6 to July 26.	Period III, July 27 to Aug. 15.
	Days.	*Days.*	*Days.*
iterval between squares on Pima, 1921...	5.36±0.113	6.45±0.115	7.53±0.132
iterval between flowers on Pima,[1] 1920...	5.91± .068	7.14± .098	8.85± .231

[1] The intervals are based on flowering periods 30 days later than the square periods used the following ar. This represents the time from appearance of square to bloom, and places the two series on a comrable basis.

The lengthening of the period between the production of new squares as just been shown to be correlated with the advance of the season. he possibility that the period lengthens because the new internodes are rther out on the fruiting branch naturally suggests itself. The interval etween the appearance of the first square on a fruiting branch and the ppearance of the second was figured for the 10 Pima plants in 1921. his interval was compared with the interval from the appearance of the cond square until the third square appeared, and so with other joints, ong the fruiting branches. A summary of these data is given in able IV.

It will be noticed that the period does increase progressively between e successive internodes of the branches. The difference, however, is ight and it is believed that the reason for the increase is that these nodes ere produced later in the season, which, as has been shown in Table III, sults in a longer interval. Such differences, however, were not found be correlated with the node numbers representing their positions on e branches.

When comparisons were made of the interval between the appearnce of squares formed during the same three-week period on the st and second nodes and on the fourth and fifth nodes of fruiting anches, it was found that the interval between squares on the outer odes of lower fruiting branches was practically the same as the interval

between squares on the first and second nodes of branches farther up on the main stalk. The mean interval between the appearance of squares on the fourth and fifth nodes was 6.2 days, while the mean interval between the appearance of squares on the first and second nodes was 6.0[illegible] days, for squares appearing within the three-week period of July 6 to July 26.

TABLE IV.—*Average interval between the successive appearance of squares for each internode on 10 Pima plants, Sacaton, Ariz., 1922*

Internodes.	Interval.
	Days.
First to second	5.6[illegible]
Second to third	6.0[illegible]
Third to fourth	[illegible]
Fourth to fifth	6.8[illegible]

DEVELOPMENT PERIOD OF THE FLORAL BUD OR "SQUARE"

The number of days from the appearance of a square [4] until it flowers is a feature in the growth of cotton that has received little attention by investigators, although it is of considerable importance in the analysis of late or early varieties and in relation to weevil damage.

In the season of 1921, the "square period"—as the interval between the appearance of the square and the date of flowering has been termed—was recorded for several varieties of cotton at Sacaton, Ariz. The information was obtained on three Upland varieties for squares that appeared between June 15 and July 10 and for squares of Pima cotton between June 15 and August 15. (See Plate 1, showing the early development of Pima floral buds.) These data are presented in Table V, giving the mean square period as obtained from the above data. It will be noticed that the mean period for Pima was 30.11 days, while that of the three Upland varieties was about 23 days, a difference of approximately 7 days. From similar data obtained on James Island, near Charleston, S. C., the mean square period for Sea Island was found to be 33.06 days and for Meade cotton 28.45 days. Such data illustrate in a practical way one of the principal reasons why the Sea Island and Egyptian types of cotton are later than the Upland varieties.

TABLE V.—*Interval from appearance of squares until flowering date*

Variety.	Locality.	Year.	Mean square period.
			Days.
Lone Star	Sacaton, Ariz	1921	23.20±0.[illegible]
Acala	....do	1921	22.80±.[illegible]
Durango	....do	1921	23.40±.[illegible]
Pima Egyptian	....do	1921	30.11±.1[illegible]
Sea Island	South Carolina	1922	33.04±.1[illegible]
Meade	....do	1922	28.45±.[illegible]

[4] The term "appearance of a square" is used in this paper to designate the time that the three bracts of a fruiting bud become visible to the naked eye as a minute triangular form, approximately one-thirty-second inch in diameter.

In order to see if there was a lengthening of the square period as the season advanced, the data relating to the Pima variety were divided and compared in three successive three-week intervals. As shown in Table VI, the mean square period from June 15 to July 5 was 28.32 days, from July 6 to July 26, 31.11 days, and from July 27 to August 15, 31.43 days. From these data it appears that the square period is shorter early in the season than later, but that the increase of the third three-week interval is not significantly greater than that of the second three-week interval. This relation could not be determined in the other varieties, since the data were not recorded for sufficiently long intervals.

TABLE VI.—*Mean square period for three 3-week interval of Pima at Sacaton, Ariz., 1921*

	Squaring period.		
	Period I, June 15 to July 5.	Period II, July 6 to July 26.	Period III, July 27 to Aug. 15.
Mean number of days	28.32±0.115	31.11±0.067	31.43±0.115

A further comparison of the mean period required for the development of squares on the successive internodes of the fruiting branches was made on the Pima at Sacaton in 1921. These data are summarized and presented in Table VII. The mean square period at each node is seen to increase slightly after the second node. This increase, however, is regarded as being due to the fact that the squares on the outer internodes were produced later, and it has been previously shown that the later squares have a longer square period regardless of their position on the fruiting branches. From these data there is no significant evidence that the square period is longer because the square is produced at the outer nodes, toward the end of the branch. This is evident when the periods for squares of first nodes are compared with periods for squares of fifth nodes that appeared on the same dates.

TABLE VII.—*Mean square period for the successive internodes of the fruiting branches on Pima, Sacaton, Ariz., 1921*

	Fruiting branch internode No.—				
	1	2	3	4	5
Mean number of days	29.4	29.4	30.1	30.7	31.1

GROWTH OF THE FLORAL BUD

A daily record of the size of floral buds was made on the Lone Star variety at Greenville, Tex., in 1922. The size of the bud was determined by depressing one bract of the young square and measuring the length of the bud from the base of the calyx to the tip of the corolla. Measurements were started when the bracts of the square were about

10 mm. in length. The length of the floral bud in these young squares varied only slightly, the average length being about 6 mm. Daily measurements were taken during the development of the bud until it flowered. The interval between the time when the bud was 6 mm. in length and the time when it flowered was found to be about 15 days. No case was found in which this interval exceeded 15 days and only 3 buds out of 24 flowered in a shorter interval.

The mean length of floral buds was computed from the daily measurements of all buds. From these data, which are presented in Table VIII, the mean daily length of the bud may be determined for a period of 15 days preceding bloom. From the differences between the lengths of the bud on successive days, the average daily growth rate can be computed. From the fifteenth to the tenth days preceding bloom, the average daily growth of the bud is approximately 0.5 mm. After the tenth day, the daily growth rate increases slowly until the fourth day before the opening of the flower, at which time the mean length of the bud was 14.28 mm. Growth is rapid thereafter. The mean length of the bud on the day preceding bloom was 24.37 mm., representing a total increase in length of the bud of about 10 mm. during the last 3 days before bloom. The rapid growth of the bud during the last few days is due to the enlargement of the corolla and the inclosed staminal column.

The size of the floral bud is of importance in connection with studies of boll-weevil infestation. It is believed that the buds are not large enough to breed weevils until they have attained a length of about 6 mm. Squares with buds smaller than this have the bracts closely appressed and seldom are entered by the weevils. Also, the buds are too small for the full development of weevil larvae.

Although records were not kept on the date of appearance of squares it is believed that the first stage recorded in Table VIII represents about the tenth day after the appearance would have been recorded. On this basis the first 10 or 12 days of square growth may be considered as affording no opportunity for the development of a new generation of weevils. Following this period, the square develops through a period of 15 days, during which time it is of sufficient size to permit a larva to develop.

TABLE VIII.—*Growth of floral bud of the Lone Star variety shown by the daily in[illegible] in length, Greenville, Tex., 1922*

Number of days preceding bloom.	Mean length of floral bud.	Number of days preceding bloom.	Mean length of floral bud.
	Mm.		*Mm.*
15	6.02	7	11.17
14	6.57	6	12.22
13	7.2	5	13.1
12	7.62	4	14.28
11	8.36	3	15.6
10	8.96	2	17.7
9	9.67	1	24.37
8	10.3		

GROWTH OF LONE STAR BOLLS IN TEXAS

Two series of measurements of the growth of bolls were obtained on the Lone Star variety near Greenville, Tex., 1922, one series representing the growth of bolls at the beginning of the flowering season, the other of bolls produced from later flowers, the last that were able to set bolls under the local conditions of drought. Measurements of boll length were recorded the second day after the bloom, and continued daily until it was certain that the maximum length had been attained. The young bolls at 2 days of age were about 16 mm. long, increasing in length approximately 2 mm. per day thereafter until they were about 12 days old, or about 37 mm. long. After reaching this age the growth rate was much slower, the average maximum boll length of about 41 mm. having been recorded 8 days later, or 20 days after the date of flowering. Table IX presents the mean daily length of these bolls.

It is interesting to note that no increase in length was found after the twentieth day from the bloom. Many bolls reached their full length in 10 days, the mean period from bloom to maximum length being 17.3 days in the first series of bolls and 17.1 days in the second. Of course, these records should not be taken to indicate that development of the boll is complete when the full length is reached, since 17 days represent less than half of the period from the bloom to the open boll.

TABLE IX. *Daily increase in length of Lone Star bolls, Greenville, Tex., 1922*

Number of days after flowering.	Length of bolls from blooms open July 21 to July 26.	Length of bolls from blooms open Aug. 3 to Aug. 8.
	Mm.	*Mm.*
2	17.6	14.77
3	19.77	16.77
4	21.35	18.18
5	23.55	19.4
6	25.67	20.77
7	28.62	22.2
8	30.02	24.73
9	32.27	26.45
10	33.82	28.55
11	36.1	30.95
12	37.9	34.16
13	39.05	35.68
14	40.35	36.68
15	41.15	37.5
16	41.85	38.27
17	42.25	38.86
18	42.67	39.13
19	43.15	39.27
20	43.17	39.36

MATURATION PERIOD OF LONE STAR BOLLS

It will be noted in Table IX that the later bolls are consistently smaller than the early ones. This shows the inhibiting effect of the drought which checked the growth of plants after the first week in August. The smaller size of the bolls, however, did not result in a shorter period of maturation. Data on the number of days from bloom to open boll,

show that the bolls produced during the late flowering period were actually slower in maturing than the early bolls. The mean number of days between bloom and open boll for flowers opening from July 21 to July 26 was found to be 42.57 days, while that for bolls set from August 3 to August 8 was 44.55 days. A probable error of ±0.068 days and ±0.23 days, respectively, was obtained on these means. These determinations show that the increase of 1.98 days in the maturation period of the later bolls is eight times the probable error of the difference, indicating that it is significant.

No rain occurred throughout the maturation period of either the early or late bolls, and the increase of about two days in the period of maturation of the late bolls may have been due to the checking of plant growth by drought. This suggests that boll opening was not due primarily to the effect of atmospheric conditions in drying the bolls. Excessive shade or moisture, or lower temperature, undoubtedly tends to defer boll opening, but under consistently dry conditions a longer interval between bloom and open boll in later bolls may be due to a retarding of growth processes. It might be expected that drought would result in a premature opening of bolls, but the results obtained at Greenville did not indicate any such effect. It is probable, however, that more severe conditions would result in premature opening.

GROWTH OF PIMA BOLLS IN ARIZONA

Other data on the growth of bolls were obtained from the Pima Egyptian variety at Sacaton, Ariz., in 1921. These records include determinations of the volume, green weight, and dry weight of the growing bolls at regular intervals after flowering.

Table X presents the average volume and weight of Pima bolls as determined from 60 boll samples collected at five-day intervals. From this table it can be seen that the average Pima boll grows very rapidly, reaching its mean maximum volume of 14 cc. at the age of 25 days. Even at 15 days the bolls are nearly full size. (Pl. 2.) The growth, however, as shown by green weight is not so rapid, the mean maximum of 13.4 gm. being obtained at the age of 40 days. Measured by dry weight, the growth is even less rapid, and the mean maximum of 5.? gm. is not reached until 50 days of age.

It is evident from these data that the average Pima boll reaches its maximum volume in less than half of the period between the date of flowering and opening of the boll. The green weight of bolls attains a maximum and then declines before maturity is reached. Growth in dry weight gives the best index of progress toward mature development, the maximum of dry weight of the average boll being attained at least 10 days before opening.

TABLE X.—*Volume, green weight, and dry weight per boll at 5-day intervals of Pima cotton at Sacaton, Ariz., 1921, based on the average of 60 bolls of each age that flowered in August*

Age of boll.	Volume.	Green weight.	Dry weight.
Days.	*Cc.*	*Gm.*	*Gm.*
5	.87	.72	.12
10	3.14	2.96	.45
15	8.91	7.93	1.26
20	12.59	11.02	1.99
25	14.66	12.86	2.56
30	14.60	12.93	2.82
35	14.65	13.03	3.12
40	14.90	13.45	3.36
45	14.80	13.15	3.76
50	14.65	13.16	3.98
55	14.10	12.14	3.99
60	....	10.30	3.83
65	....	[1] 4.53	3.99

[1] Open bolls.

MATURATION PERIOD OF PIMA BOLLS

A range in the period of maturation from 45 days to 80 days was obtained on normal Pima bolls in this study, with the period lengthening for the bolls of later flowering dates. This is in agreement with results reported by King,[5] who found that the period of maturation of Pima bolls in Phoenix, Ariz., varied from 54 days for those bolls set in July to 82 days for those set in September. Sufficient data were secured in 1921 on bolls of different flowering dates to indicate that at least three factors are involved in the lengthening of the period of maturation of Pima bolls at Sacaton. First, the early bolls were smaller than those set later in the season; second, the early bolls attained full structural development in fewer days than those set later; and third, the early bolls showed a more rapid reduction of the boll moisture after reaching mature structural development, so that the opening stage was reached in fewer days.

GROWTH OF SEA ISLAND AND MEADE COTTON BOLLS IN SOUTH CAROLINA

The growth of Sea Island and Meade bolls near Charleston, S. C., in 1922, is shown in Table XI, which gives the mean volume and weight per boll of 50 boll samples collected at seven-day intervals. It can be readily seen from this table that the bolls grow very rapidly to full size, as in the other experiments. The Sea Island bolls reach their mean maximum volume of 19 cc. at 21 days of age, and the Meade bolls also attained their larger volume of 29 cc. in the same number of days.

In comparing the time required for bolls to reach full size, these data are only slightly different from those obtained with the Lone Star variety at Greenville, where the full size was reached in about 20 days. There is more contrast with the data secured from the Pima cotton at Sacaton, where the mean maximum volume was found to be reached at the age of 25 days.

[5] KING, C. J. WATER-STRESS BEHAVIOR OF PIMA COTTON IN ARIZONA. U. S. Dept. Agr. Bul. 1018, 24 p., 6 fig., 4 pl. 1922. Literature cited, p. 23–24.

TABLE XI.—*Volume and green weight per boll at seven-day intervals of Sea Island and Meade cotton, near Charleston, S. C., 1922, based on the average of 50 bolls collected at each age*

Age of boll.	Sea Island.		Meade.	
	Volume.	Green weight.	Volume.	Green weight.
Days.	*Cc.*	*Gm.*	*Cc.*	*Gm.*
7	2.40	2.24	4.78	4.26
14	13.13	10.91	21.00	18.23
21	19.95	16.16	29.22	26.64
28	18.50	15.65	30.30	27.53
35	19.63	15.81	30.63	27.88
42	19.61	15.88	29.53	26.65
49	19.00	15.23	....	22.70
56	....	[1] 6.70	....	....
63	....	[1] 5.70	....	....

[1] Open bolls.

MATURATION PERIOD OF SEA ISLAND AND MEADE BOLLS

A mean maturation period of 57.6 $\pm$0.013 days was obtained for Sea Island bolls near Charleston in 1922, from data recorded from bloom to open boll on 988 bolls. The period of maturation showed a definite increase as the season advanced. A mean period of 56.9 days was obtained from bolls set from flowers blooming between June 22 and 25, while a mean period of 62.6 days was found for those set from flowers blooming between August 3 and August 6. The probable errors for these periods were $\pm$0.23 days and $\pm$0.60 days, respectively, showing that the increase in the period of maturation is significant and not due to chance.

The mean period of maturation for the Meade variety at Charleston in 1922 was 56.14 days, as determined from 277 bolls, with a probable error of $\pm$0.11 days. A tendency for the period of maturation to increase as the season advanced was noted, but the data are not presented on account of the small number of bolls and the shortness of the period during which they were set. It is of interest to note that there is a difference of only one day between the mean maturation period of Sea Island and Meade bolls in this location. In other words, the Sea Island bolls require, on the average, about one day longer to open than the Meade bolls.

SUMMARY

(1) Data relating to the growth of the cotton plant are given, including the rate of floral bud production, the period of development from the appearance of a floral bud to flower, and the growth of the boll from flower to maturity. This information is needed in connection with cultural methods and weevil control problems.

(2) A comparison of similar phases of plant growth and development was obtained on several varieties under widely different environmental conditions—namely, Lone Star, Acala, Durango, and Pima Egyptian at Sacaton, Ariz., in 1921 and 1922; Lone Star, near Greenville, Tex., in 1922; and Meade and Sea Island near Charleston, S. C., in 1922.

(3) The average number of days between the production of successive fruiting branches was approximately three days, with none of the varieties showing significant differences. (See Table I.)

(4) All the varieties, under the conditions represented, showed an average of about six days between the appearance of successive squares on the fruiting branch. (See Table II.)

(5) The Pima variety in Arizona showed a tendency for the interval between the appearance of successive squares of the fruiting branches to lengthen as the season advanced. (See Table III.)

(6) A comparison of the interval between the appearance of successive squares on the fruiting branches showed that the interval increases progressively along the branch. This increase may be due to the fact that outer squares are produced later in the season when growth is slower. The intervals between squares that are produced at the same dates are approximately equal regardless of the positions of the squares on the branches. (See Table IV.)

(7) The interval between appearance of a square and its date of flowering, termed the "square period," showed consistent differences between varieties. The square period for Sea Island was approximately 33 days, for Pima 30 days, for Meade 28 days, and for Lone Star, Acala, and Durango 23 days. (See Table V.)

(8) A tendency for the square period to lengthen as the season advanced was noted on the Pima variety at Sacaton. (See Table VI.) This relation could not be determined in the other varieties since the data were not recorded for sufficiently long intervals.

(9) A slight increase in the square period for each successive node of the fruiting branch was also found on the Pima cotton at Sacaton, but this is probably due to the squares being produced later in the season, and is not correlated with position on the branch. (See Table VII.)

(10) Growth rates of floral buds of Lone Star cotton at Greenville, Tex., showed that the buds grew at a nearly constant daily rate until within about 3 days of flowering, when a more rapid growth rate was recorded.

(11) The sizes of the floral buds at different ages indicate that they were not large enough to successfully develop weevil larvae until about 15 days before flowering, or approximately 10 days after the squares appear.

(12) The growth of Lone Star bolls in Texas was very rapid, the mean maximum length of 41 mm. being reached about 20 days after flowering. The early bolls were found to be larger, the later bolls being produced during a drought. Although smaller, the late bolls had a longer maturation period, 44.55 days, while the large early bolls showed a mean maturation period of 42.57 days, or about 2 days less than the late bolls.

(13) Data on the growth of Pima bolls in Arizona were determined by records of volume, green weight, and dry weight of growing bolls, at regular intervals after flowering. The results show that the mean maximum volume per boll, 14 cc., was attained in 25 days after flowering; that the mean maximum green weight per boll, 13.4 gm., was attained in about 40 days; and that the mean maximum dry weight per boll, 3.8 gm., was attained in about 50 days.

(14) A range in the period of maturation from 45 days to 80 days was observed on normal Pima bolls in Arizona in 1921. The period of maturation was found to lengthen for bolls of later flowering dates.

(15) Three factors seemed to influence the lengthening of the maturation period for Pima bolls in 1921: The early bolls were smaller; they reached mature structural development in fewer days; and they reduced boll moisture to the opening stage more rapidly than the later bolls.

(16) The growth of Sea Island and Meade cotton bolls was determined in South Carolina during 1922 by recording the volume and green weight of growing bolls collected at seven-day intervals after flowering.

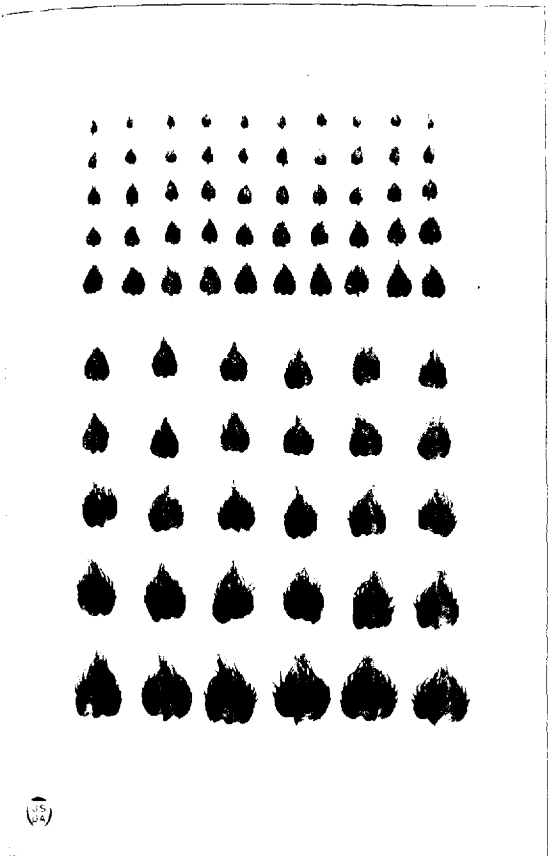
(17) The Sea Island bolls reached their mean maximum volume of about 19 cc. and their mean maximum green weight of about 16 gm. in 21 days after flowering.

(18) The Meade bolls reached their mean maximum volume of about 29 cc. in 21 days and their mean maximum green weight of about 27 gm. in 28 days after flowering.

(19) A mean maturation period of 57.6 days was obtained for the Sea Island bolls, in comparison with 56.14 days for the Meade bolls, and the period of maturation was found to increase as the season advanced.

PLATE I

Floral buds of Pima (Egyptian) cotton at Sacaton, Ariz., showing the daily increase in size of the involucre during the early stages of growth, for 10 successive days, from the second to the eleventh day from the "appearance" of the "square." Natural size. Photographed by H. F. Loomis.



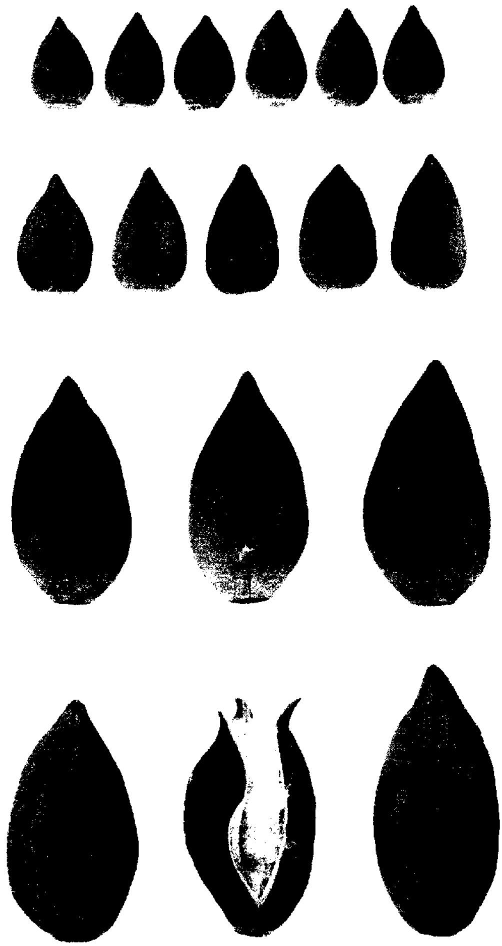


PLATE 2

Bolls of Pima (Egyptian) cotton at Sacaton, Ariz., showing the size at different stages of development. Beginning at the top row, the ages are 5, 10, 15, and 45 days, respectively, as measured from the flowering date. Natural size. Photographed by R. D. Martin.